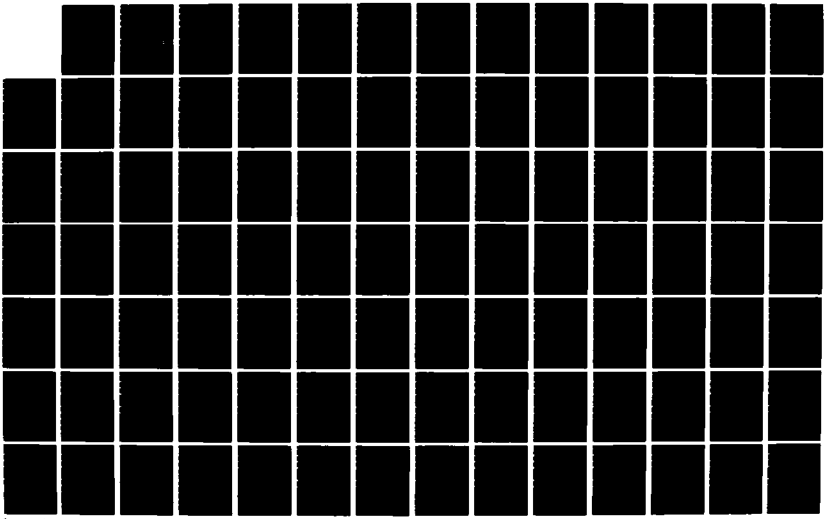
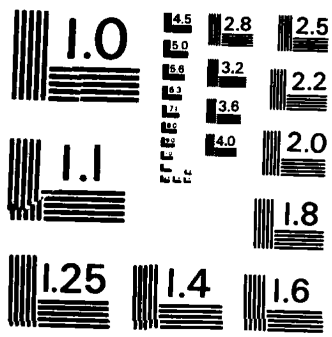
AD-A166 743 SECULAR CLIMATIC PATTERNS OF THE NORTH CENTRAL GREAT PLAINS AND THE CONTINENTAL US(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH K J PRANER 1985 1/2

UNCLASSIFIED AFIT/CI/NR-86-51T F/G 4/2 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0

AD-A166 743

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/CI/NR 86-51T	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Secular Climatic Patterns of the North Central Great Plains and the Continental U.S.		5. TYPE OF REPORT & PERIOD COVERED THESIS/DISSERTATION
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Karen J. Praner		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: Texax A&M University		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433-6583		12. REPORT DATE 1985
		13. NUMBER OF PAGES 157
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC ELECTE APR 23 1986 S A D

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

LYNN E. WOLAVER 11 April 86
Dean for Research and Professional Development
AFIT/NR, WPAFB OH 45433-6583

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Secular Climatic Patterns of the North Central Great Plains and the Continental U.S. (1985) 157pp

Karen J. Praner
Capt, USAF

Texas A & M University, College Station, TX
Master of Science Degree

Monthly mean maximum and minimum temperatures and total precipitation data (1900-1970) were compiled for 144 carefully selected stations in the continental U.S. The north central great plains (NCGP) was divided into regions of similar temperature and precipitation patterns using 39 stations representative of the NCGP. In a like manner, the 144 U.S. stations were grouped into regions with similar patterns of mean annual temperature and total annual precipitation; weighted mean annual temperature and total precipitation series were derived by area-weighting the regional series.

Comparison of regional and mean series revealed marked differences between series. Tests of normality and homogeneity of means were conducted for the mean annual temperature and total annual precipitation series; it was determined that several distinctly different periods of temperature and precipitation existed between 1901 and 1970 for both series. The presence of consecutive periods of dissimilar climatic patterns within the 70-year series of climatic elements implies that climate exhibits jump discontinuities which must be explored.

Major references:

Lawson, M. P., R. C. Balling, JR., A. J. Peters and D. C. Rundquist, 1981: Spatial analysis of secular temperature fluctuations. J. Clim., 6, 325-332.

Mitchell, J. M., Jr., 1963: On the world-wide pattern of secular temperature change. Changes of climate, U.N.E.S.C.O., Arid Zone Research Series XX, Paris, 161-181.

Willett, H. C., 1950: Temperature trends of the past century. Cent. Proc. Roy. Meteor. Soc., 195-206.

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to ascertain the value and/or contribution of research accomplished by students or faculty of the Air Force Institute of Technology (AU). It would be greatly appreciated if you would complete the following questionnaire and return it to:

AFIT/NR
Wright-Patterson AFB OH 45433

RESEARCH TITLE: ______________________________

____

AUTHOR: ______________________________

RESEARCH ASSESSMENT QUESTIONS:

1. Did this research contribute to a current Air Force project?

( ) a. YES ( ) b. NO

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not?

( ) a. YES ( ) b. NO

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency achieved/received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

( ) a. MAN-YEARS ________ ( ) b. $________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3. above), what is your estimate of its significance?

( ) a. HIGHLY SIGNIFICANT ( ) b. SIGNIFICANT ( ) c. SLIGHTLY SIGNIFICANT ( ) d. OF NO SIGNIFICANCE

5. AFIT welcomes any further comments you may have on the above questions, or any additional details concerning the current application, future potential, or other value of this research. Please use the bottom part of this questionnaire for your statement(s).

____
NAME GRADE POSITION

____
ORGANIZATION LOCATION

STATEMENT(s):

FOLD DOWN ON OUTSIDE - SEAL WITH TAPE

AFIT/NR
WRIGHT-PATTERSON AFB OH 45433

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE. $300

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 73236 WASHINGTON D.C.

POSTAGE WILL BE PAID BY ADDRESSEE

AFIT/ DAA
Wright-Patterson AFB OH 45433

FOLD IN

SECULAR CLIMATIC PATTERNS OF THE

NORTH CENTRAL GREAT PLAINS AND

THE CONTINENTAL U.S.

A Thesis

by

KAREN JEAN PRANER

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 1985

Major Subject: Meteorology

SECULAR CLIMATIC PATTERNS OF THE

NORTH CENTRAL GREAT PLAINS AND

THE CONTINENTAL U.S.

A Thesis

by

KAREN JEAN PRANER

Approved as to style and content by:

John F. Griffiths

John F. Griffiths
(Chairman of Committee)

James P. McGuirk

James P. McGuirk
(Member)

R. J. Freund

Rudolf J. Freund
(Member)

James R. Scoggins

James R. Scoggins
(Head of Department)

December 1985

ABSTRACT

Secular Climatic Patterns of the

North Central Great Plains and

the Continental U.S. (December 1985)

Karen J. Praner, B.S., Eastern New Mexico University;

B.S., The Pennsylvania State University

Chairman of Advisory Committee: Professor John F. Griffiths

Monthly mean maximum and minimum temperatures and total precipitation data (1900-1970) were compiled for 144 carefully selected stations in the continental U.S. The north central great plains (NCGP) was divided into regions of similar temperature and precipitation patterns using 39 stations representative of the NCGP. In a like manner, the 144 U.S. stations were grouped into regions with similar patterns of mean annual temperature (7 regions) and total annual precipitation (6 regions); weighted mean annual temperature and total precipitation series were derived by area-weighting the regional series.

Comparison of regional and mean series revealed marked differences between series. Tests of normality and homogeneity of means were conducted for the mean annual temperature and total annual precipitation series; it was determined that several distinctly different periods of temperature and precipitation existed between 1901 and 1970 for both series. The presence of consecutive periods of dissimilar climatic patterns within the 70-year series of climatic elements implies that climate exhibits jump discontinuities which must

be explored.

DEDICATION

To Dave and Mom, specialists in support and encouragement.

ACKNOWLEDGEMENTS

I am grateful to the National Science Foundation for supporting this research under Contract Grant Number ATM-8117008. The aid of innumerable assistants made possible the completion of this project. The many hours they spent typing and estimating data provided the computerized data base used as a basis of this study.

Mrs. Dorothy Lorenz and Dr. Charles E. Cichra made corrections to the text and figure headings to finalize the work; my husband, Dave Praner, was instrumental in coordinating the finalization effort. Without his endeavor this project surely would not have been completed.

A special thanks to the members of my committee, Professor John F. Griffiths, Dr. James P. McGuirk, and Dr. Rudolf J. Freund. Each committee member spent several hours discussing possible approaches to various aspects of the project. Dr. Freund was ever ready with advice on statistical problems I encountered. Dr. McGuirk's enthusiasm for meterology and his expertise in climatological applications to other areas of meteorology were an inspiration to me. Particular thanks to Professor Griffiths, the head of my committee. He, more than any other, deserves credit for bringing this project to its culmination. He kept me on course thoughout the project and spent a great deal of time advising and directing my efforts. His time spent working out tedious last-minute details is greatly appreciated.

TABLE OF CONTENTS

ABSTRACT iii

DEDICATION v

ACKNOWLEDGEMENTS vi

TABLE OF CONTENTS. vii

LIST OF TABLES ix

LIST OF FIGURES. x

1. INTRODUCTION 1

a. Determining climatic trends. 1
b. Regionalization and comparison of trends 2
c. Objectives of research 3
d. Homogeneous data 4
e. Present status of the question 5

2. DATA 7

a. Selection criteria 7
b. Sources 12
c. Representation and verification of data 17

3. GROUPING OF CLIMATOLOGICAL DATA 19

a. Introduction 19
b. Grouping Methods 19
c. Analysis of grouping methods 27

4. STATISTICAL METHODS 33

a. Tests of normality 33
b. Tests of homogeneity of variance and mean 35
c. Correlation coefficients 38
d. Time series analysis 39

5. ANALYSIS 46

a. Analysis of North Central Great Plains data 46
b. Analysis of U.S. data 46
c. Analysis of grouped and area-weighted U.S. data 52
d. Trends in regional and overall annual data 69

TABLE OF CONTENTS (Continued)

6. CONCLUSIONS AND RECOMMENDATIONS 86

a. Conclusions 86
b. Recommendations 89

REFERENCES. 91

APPENDIX

A 94

B 103

C 107

D 109

E 111

F 116

G 120

H 135

I 137

J 155

VITA. 158

LIST OF TABLES

TABLE Page

1 Reference stations with station identifiers and latitudes and longitudes 8

2 Reliability of the estimating procedure. (Examples of how well estimates approximate actual observations.) 16

3 Overall standard error of the mean associated with various groupings (°F) 28

4 Percentage points of the ratio, s^2max/s^2min 37

5 Conversion of r to Z 40

6 Moderate and extreme series additive factors 42

7 Results of statistical tests on overall mean series. Txa=Max Annual Temp; Txw=Max Winter Temp; Txs=Max Summer Temp; Tna=Min Annual Temp; Tnw=Min Winter Temp; Tns=Min Summer Temp; Tma=Mean Annual Temp; Tmw=Mean Winter Temp; Tms=Mean Summer Temp; Pa=Total Annual Precip; Pw=Winter Precip; Ps=Summer Precip. 46

8 Simple statistics by decade for each mean series. (Temperatures are represented as deviations from their 70-year means.) . . . 49

9 t-ratios of orverall mean series 53

10 Part I Pearson correlation coefficients of mean annual temperature for each region of similar temperature versus each of the other regions and the overall mean 60

Part II Pearson correlation coefficients of total annual precipitation for each region of similar precipitation versus each of the other regions and the overall mean 60

11 Means of previously determined periods of similar temperature and precipitation for overall mean (weighted) series and for regions. (Temperatures are in °F. Precipitation is in in..) 82

LIST OF FIGURES

FIGURE Page

1a U.S. Reference Stations. (See Table 1 for station names) . . 13

1b Nebraska and South Dakota reference stations. (See Table 1 for station names) 14

2 Regions of maximum and minimum temperature for the NCGP determined by cluster analysis. 21

3 Regions of total precipitation for the NCGP determined by cluster analysis. 22

4 Regions of mean minimum and mean maximum temperature for the NCGP determined from climatological division (solid lines) and from the cluster method (dashed lines). 24

5 Regions of total precipitation for the NCGP determined from climatological division (solid lines) and from the cluster method (dashed lines). 25

6a Regions of mean minimum temperature for the NCGP determined by cluster analysis using differenced data. 26

6b Regions of mean minimum temperature for the NCGP determined by correlation of differenced data. 26

7 Regions of mean annual temperature for the U.S. as defined by the correlation method. Values of constant correlation (overall mean of 144 U.S. stations vs. individual stations) are provided in association with isopleths denoting regional boundaries. (Underlined numbers indicate region numbers which will be used in future references.) 31

8 Regions of total annual precipitation for the U.S. as defined by the correlation method. Values of constant correlation (overall mean of 144 U.S. stations vs. individual stations) are provided in association with isopleths denoting regional boundaries. (Underlined numbers indicate region numbers which will be used in future references.) 32

9 Average ratio, mean deviation/σ, and limits for 0.95 probability in a sample from a normal distribution (from Geary, 1935). . . 34

LIST OF FIGURES (Continued)

FIGURE Page

10 Various smoothings of mean maximum temperature for Columbus, KA (1900-1970). Abscissa = Year; Ordinate = Temperature in °F. . 44

11 Minimum annual temperature plotted on normal probability paper. 48

12a Overall mean annual temperature for 144 U.S. stations. 55

12b Areally-weighted mean annual temperature for 144 U.S. stations. 56

13a Percentage of 70-year U.S. total mean annual precipitation 1901-1970. 57

13b Percentage of area-weighted 70-year U.S. total mean annual precipitation 1901-1970. 58

14a Mean annual temperature for CACE 1901-1970. 62

14b Mean annual temperature for CODE 1901-1970. 63

14c Mean annual temperature for FLCL 1901-1970. 64

14d Mean annual temperature for ORHR 1901-1970. 65

14e Mean annual precipitation for FLCL 1901-1970. 66

14f Total annual precipitation for NDND 1901-1970. 67

14g Total annual precipitation for WAOL 1901-1970. 68

15 Areally-weighted mean annual temperature for the U.S. (From Diaz and Quayle, 1980). 70

16a Yearly pattern of differences from the 70-year mean annual maximum temperature for the 144 U.S. stations, 1901-1970. . . 71

16b Yearly pattern of differences from the 70-year mean annual minimum temperature for the 144 U.S. stations, 1901-1970. . . 72

17a Standard errors of the means of mean maximum temperature, 1901-1970. 74

LIST OF FIGURES (Continued)

FIGURE Page

17b Standard errors of the means of mean minimum temperature, 1901-1970. 75

18a Standard errors of the means for mean maximum temperature expressed as a difference of the 70-year mean. 77

18b Standard errors of the means for mean minimum temperature expressed as a difference of the 70-year mean. 78

19 Periods of similar temperature for the U.S., 1901-1970. . . . 79

20 Periods of similar precipitation for the U.S., 1901-1970, using the differences from the 70-year area-weighted mean. 80

21 Willett and Mitchell's differencing of non-overlapping pentads applied to the mean annual temperature series of this study. . 85

1. INTRODUCTION

a. Determining Climatic Trends

The issue of global climatic trend has been of particular scientific interest since Willett published his paper, "Temperature Trends of the Past Century" (Willett, 1950). Since then numerous others have re-examined and updated their findings. The most notable of these is Mitchell (1961, 1963), who took part in Willett's original study. The investigation of long term precipitation trend was undertaken by Kraus (1954, 1955a, 1955b), but did not invoke the same magnitude of interest in scientific literature as did Willett's publication. Generally, only one climatic element is studied in trend research; Diaz and Quayle (1980) produced one of the few reports of climatic trend which deals with both temperature and precipitation.

Willett computed average temperatures in each latitude band to cite evidence of global climatic change. The major shortcomings of his approach are the lack of station coverage in each band, disregard for representation of ocean areas, and lack of a trend comparison of stations within each band. Although Willett's method is subject to substantial uncertainty, the general approach he took has been used by the investigators who succeeded him in this research. Mitchell used Willett's method, but included weighting of data by area of each latitude band. He augmented Willett's data set with inclusion of additional stations to give a more uniform distribution of data sets.

The citations on the following pages follow the style of the Journal of Climate and Applied Meteorology.

Mitchell's results echoed Willett's, but the estimate of the magnitude of global temperature increase from 1880 to 1940 was reduced by approximately 20% to 0.8°F for mean annual temperature and approximately 1.2°F for mean winter temperature. Budyko (1982) used maps of air temperature anomalies to reach the same conclusion for trend of increasing temperature between 1880 and 1940, and a trend of decreasing temperature since 1940. Budyko's only statement about reliability of conclusions of temperature trends concerns the quality of the data used. He stated that "...observational data from hundreds of stations that cover more or less evenly land and ocean are necessary for reliable estimation of trends in mean air temperature variations." Callendar (1961) used Willett's general method with Mitchell's area-weighting. He smoothed data with 5-year overlapping averages adjusted by a nonlinear weighting and found the same general trends Willett had found.

Kraus (1954, 1955a, 1955b) did a regional and station by station analysis of precipitation by season. He related his findings of rainfall anomalies with a shift in the mean upper westerlies. The sharp decline in rainfall in eastern Australia he observed for the last years of the 19th century also was observed in the early 20th century extending up the east coast of North America. Kraus's findings for North America were based on 5-year means for only four U.S East Coast stations.

b. Regionalization and comparison of trends

Landsberg (1975) defined the term 'trend' as "...a one-sided move

of an element, upward or downward." He continued by stating that "In any climatic series such trends are usually completely masked by the iterations and fluctuations (within the series)." The classical method of investigating climatic trend has involved the use of overall means of latitude bands to determine global or regional trends. An approach suggested by Lawson et al. (1981) entails the identification of regions of temporal variations in secular temperature records. They contend that much information is lost when investigators combine all their information in order to produce a global or regional trend for a large area. Lawson used 27 NOAA benchmark stations 'uniformly' distributed across the U.S. and found nine different regions of temperature trend in the U.S. between 1912 and 1971. The stations within Lawson's regions each displayed individuality from the others in the same region. More recently, Walsh et al. (1982) did a regionalization of precipitation stations based on factor analysis and orthogonal rotation to pre-established criteria; the patterns of spatial coherence they found agreed well with previously documented cyclone trajectories and drought index patterns.

c. Objectives of Research

The purposes of this research are to:

(1) Compile monthly mean maximum and minimum temperatures and total precipitation (1900-1970) data for continental U.S. stations that are carefully selected according to specific criteria;

(2) Apply various grouping techniquies to data from the North Central Great Plains (NCGP) to determine an appropriate method which will be used to group stations of similar temperature and

precipitation in the continental U.S.; and

(3) Analyze the pattern of climatic fluctuations for the continental U.S. in the period 1901-1970 for mean maximum and minimum temperatures and total precipitation using winter (DJF), summer (JJA) and annual data.

d. Homogeneous Data

According to Conrad and Pollak (1962), a numerical series representing the variations of a climatological element is called homogeneous if the variations are caused only by variations of weather and climate. Mitchell (1963) pioneered the study of effects of lack of homogeneity in comparisons of climatic trends. Researchers in the field of climatic trend analysis have acknowledged the fact that homogeneous data are necessary for accurate conclusions. However, as stated by Love (1985), "...it is generally impossible to determine whether or not a series of observations exhibits absolute homogeneity." For this reason the word homogeneity as used in climatological studies is usually, strictly, relative homogeneity. This term is defined by Conrad and Pollak in the following manner - "a climatological series exhibits relative homogeneity with respect to a synchronous series at another nearby location if the difference (or ratio) of pairs of homologous (like variable over same time period) averages constitute a series of random numbers that satisfies the law of errors." This definition assumes that non-natural variability is unlikely to occur simultaneously at two sites. 'Nearby' must be defined such that the two sets of station data are assumed to sample the same climate.

Previous researchers have used readily available climatic data in their studies. When homogeneity was addressed, it usually was simply as an acknowledgement that lack of homogeneity in the data being analyzed would cause some error in the trends established. Lawson et al. (1981) were careful to include only benchmark stations in their study, however, these stations are less than adequate in terms of Conrad and Pollak's definition of homogeneity. The present study is one of the first to utilize data from stations carefully chosen to exclude any with obvious sources of inhomogeneity.

e. Present Status of the Question

Kellogg (1977) discussed climatic trends resulting from anthropogenic factors. His report intimates that we may be changing the climate; we must deal with this real possibility. Volcanic dust and increased CO_2 in the atmosphere as well as sunspot activity have been examined as possible causes of climatic trend. However, the announcement of a global change in temperature trend is not to be heralded with preparations for impending doom. It is postulated here that any such proclamations derived from currently available secular temperature data include an amount of error which certainly modifies the impact of such statements. Little research has been done on climatic trends using data from stations carefully chosen for homogeneity; previous researchers have given only cursory attention to the subject of reliability of their established trends.

The basic assumption in all trend research has been that a small set of stations evenly distributed around the globe provides an acceptable representation for climate trend over the entire world.

Angell and Korshover (1975) compared two sets of six stations between 40°N and 60°N. The fact that the two series agreed well led them to state that temperature trend within a 20 degree latitude band could be determined within 1°C with the use of only six evenly distributed stations. Landsberg and Mitchell (1961) maintained that the use of 120 to 180 stations represented the world's temperature trend as well as the 600 Callendar (1961) used. They made this statement on the basis of comparison of Callendar's results with Willett's (1950) and Mitchell's (1961). Mitchell conceded that the pattern of temperature change produced by his study may not have been indicative of planetary average conditions due to the large ocean areas that were not represented in his research.

2. DATA

a. Selection Criteria

The stations used in this study were selected from Love's (1985) list of candidate stations. Close inspection of the Substation History, U.S. Department of Commerce (1956), population estimates from the 1980 census, and scrutiny of data were required to determine which of Love's candidate stations met the rigid criteria set for acceptance as a reference station:

1. In rural areas; population in 1980 no greater than 5000.
2. Moves of station judged (by Cooperative Program Manager) acceptable. For this study no station with moves of more than five miles was acceptable.
3. Observers not judged poor by Cooperative Program Managers.
4. Instrument exposures not judged poor by inspectors (Co-operative Program Manager or this author).
5. Not an excessive amount of missing data. Stations were acceptable only if they did not have more than 36 months of missing data for the 71 year period. No more than four years of missing data were allowed, where a missing year was defined as one in which at least three months were missing. Also, no more than two consecutive years of missing data were allowed.

Table 1 lists the reference stations by state with their latitudes and longitudes. Also included in the listing is the abbreviation for each station which will be used to identify it in future references. The number of months with missing observations is

Table 1. Reference stations with station identifiers and latitudes and longitudes.

ID Number	Station Name	ID Letters	Latitude	Longitude
82	Highland Home, AL	ALHH	31.88N	085.47W
81	Clanton, AL	ALCL	31.95N	086.32W
59	Subiaco, AR	ARSU	35.30N	098.65W
58	Pocahontas, AR	ARPO	36.27N	090.98W
60	Prescott, AR	ARPR	33.80N	093.38W
4	Cedarville, CA	CACE	41.53N	120.17W
6	Denair, CA	CADE	37.83N	120.78W
5	Nevada City, CA	CANE	39.27N	121.02W
18	Delta,CO	CODE	38.77N	108.12W
90	Clermont, FL	FLCL	28.48N	081.78W
85	Quitman, GA	GAQU	30.78N	083.57W
84	Hawkinsville, GA	GAHA	32.28N	083.47W
83	Millen, GA	GAMI	32.87N	081.97W
43	Fayette, IA	IAFA	42.83N	091.80W
46	Corydon, IA	IACO	40.75N	093.32W
8	Ashton, ID	IDAS	44.07N	111.45W
9	Oakley, ID	IDOA	42.25N	113.88W
7	Porthill, ID	IDPO	49.00N	116.50W
92	Rockville, IN	INRV	39.77N	087.23W
93	Cambridge City, IN	INCC	39.82N	085.17W
74	Anna, IL	ILAN	37.47N	089.23W
70	Griggsville, IL	ILGR	39.72N	090.73W
69	La Harpe, IL	ILLH	40.58N	090.97W
68	Walnut, IL	ILWA	41.57N	089.58W
67	Marengo, IL	ILMA	42.25N	088.60W
73	McLeansboro, IL	ILML	38.08N	088.50W
71	Palestine, IL	ILPA	39.00N	087.62W
72	Sparta, IL	ILSP	38.13N	089.70W
66	Mt. Carroll, IL	ILMC	42.08N	089.98W
27	Columbus, KA	KACS	37.25N	094.87W
97	Greensburg, KY	KYGB	37.25N	085.50W
95	Irvington, KY	KYIR	37.88N	086.28W
96	Leitchfield, KY	KYLF	37.51N	086.30W
94	Shelbyville, KY	KYSV	38.22N	085.27W
98	Williamsburg, KY	KYWB	36.73N	084.15W
62	Melville, LA	LAMV	30.68N	091.75W
61	Plain Dealing, LA	LAPD	32.90N	093.68W
114	Woodstock, MD	MDWS	39.33N	076.87W
117	Eastport, ME	MEEP	44.92N	067.00W
116	Farmington, ME	MEFA	44.62N	070.15W
91	Allegan, MI	MIAL	42.53N	085.85W
38	Pine River Dam, MN	MNPI	46.67N	094.12W
40	Grand Meadow, MN	MNGM	43.70N	092.57W
36	Pokegama Dam, MN	MNPO	47.25N	093.58W

Table 1. (continued)

ID Number	Station Name	ID Letters	Latitude	Longitude
37	Sandy Lake Dam, MN	MNSL	46.80N	093.32W
34	Park Rapids, MN	MNPA	46.92N	095.07W
35	Leach Lake, MN	MNLL	47.25N	094.22W
54	Appleton City, MO	MOAC	38.20N	094.03W
53	Harrisonville, MO	MOHA	38.65N	094.33W
55	Lamar, MO	MOLA	37.50N	094.28W
57	Marble Hill, MO	MOMH	37.30N	089.97W
56	Arcadia, MO	MOAR	37.58N	090.62W
52	Brunswick, MO	MOBR	39.42N	093.13W
51	Louisiana Starks Nursery, MO	MOLS	39.43N	091.07W
50	Steffenville, MO	MOST	39.97N	091.88W
48	Unionville, MO	MOUN	40.48N	093.00W
78	Batesville, MS	MSBT	34.30N	089.98W
79	Pontotoc, MS	MSPT	34.25N	089.00W
80	State College, MS	MSSC	33.47N	088.80W
16	Glendive, MT	MTGL	47.10N	104.72W
106	Southport, NC	NCSP	34.00N	078.02W
22	Amenia, ND	NDAM	47.00N	097.22W
21	Napoleon, ND	NDNP	46.50N	099.77W
115	Bethlehem, NH	NHBE	44.28N	071.68W
112	Belvidere, NJ	NJBV	40.83N	075.08W
111	Charlottesburg, NJ	NJCB	41.03N	074.43W
113	Flemington, NJ	NJFL	40.52N	074.85W
20	Fort Bayard, NM	NMFB	32.80N	108.15W
109	Angelica, NY	NYAN	42.30N	078.02W
108	Hemlock, NY	NYHE	42.78N	077.62W
107	Lowville, NY	NYLO	43.80N	075.50W
110	Mohonk Lake, NY	NYML	41.77N	074.15W
100	Philo, OH	OHPH	39.83N	081.92W
99	Millport, OH	OHMP	40.72N	080.90W
28	Kingfisher, OK	OKKF	35.85N	097.93W
3	Hood River, OR	ORHR	45.68N	121.52W
86	Blackville, SC	SCBV	33.37N	081.32W
87	Kingstree, SC	SCKI	33.65N	079.82W
88	Summerville, SC	SCSV	33.03N	080.20W
89	Yemmassee 4W, SC	SCYE	32.68N	080.92W
75	Dover, TN	TNDO	36.48N	087.85W
77	Rogersville, TN	TNRV	36.42N	082.98W
76	Lewi [illegible]erg, TN	TNLB	35.45N	086.80W
31	Blanco, TX	TXBL	30.10N	098.42W
30	Llano, TX	TXLL	30.75N	098.68W
29	Ballinger, TX	TXBA	31.73N	099.97W
33	Danevang, TX	TXDA	29.05N	096.18W
32	Hallettsville, TX	TXHA	29.45N	096.93W

Table 1. (continued)

ID Number	Station Name	ID Letters	Latitude	Longitude
10	Corinne, UT	UTCO	41.55N	112.12W
15	Fillmore, UT	UTFI	38.95N	112.32W
14	Manti, UT	UTMA	39.25N	111.63W
11	Heber, UT	UTHE	40.52N	111.42W
13	Deseret, UT	UTDE	39.28N	112.65W
12	Levan UT	UTLE	39.55N	111.87W
105	Burkes Garden VA	VABG	37.08N	081.33W
104	Columbia, VA	VACO	37.77N	078.15W
103	Hot Springs, VA	VAHS	38.00N	079.83W
2	Dayton, WA	WADA	46.32N	118.00W
1	Olga, WA	WAOL	48.62N	122.80W
63	Medford, WI	WIME	45.13N	090.35W
64	Oconto, WI	WIOC	44.90N	087.95W
65	Neillsville, WI	WINE	44.53N	090.63W
102	Glenville, WV	WVGV	38.95N	080.82W
101	Wellsburg, WV	WVWB	40.30N	080.58W
17	Yellowstone Park, WY	WYYP	44.97N	110.70W
* 19	Cheyenne Wells, CO	COCW	38.82N	102.35W
41	Humbolt, IA	IAHU	42.68N	094.20W
44	Logan, IA	IALO	41.63N	095.80W
45	Mt. Ayr, IA	IAMA	40.70N	094.25W
42	Rockwell City, IA	IARC	42.40N	094.62W
23	Colby, KA	KACO	39.38N	101.07W
26	Ft. Hays, KA	KAHA	38.87N	099.33W
25	Horton, KA	KAHO	39.66N	095.52W
24	Phillipsburg, KA	KAPH	39.73N	099.32W
39	Milan, MN	MNMI	45.12N	095.93W
46	Conception, MO	MOCO	40.25N	094.68W
49	Oregon, MO	MOOR	39.98N	095.13W
144	Auburn, NE	NEAU	40.38N	095.85W
133	Broken Bow, NE	NEBB	41.42N	099.68W
139	Beaver City, NE	NEBC	40.13N	099.83W
131	Bridgeport, NE	NEBR	41.67N	103.10W
143	Crete, NE	NECR	40.62N	096.95W
141	Fairmont, NE	NEFA	40.63N	097.58W
135	Gothenburg, NE	NEGT	40.93N	100.17W
142	Geneva, NE	NEGV	40.53N	097.60W
128	Hartington, NE	NEHA	42.62N	097.27W
127	Hay Springs, NE	NEHS	42.68N	102.68W
138	Imperial, NE	NEIM	40.52N	101.63W
132	Kimball, NE	NEKI	41.23N	103.67W
136	Loup City, NE	NELC	41.28N	098.97W
130	Madison, NE	NEMA	41.83N	097.45W
140	Minden, NE	NEMI	40.50N	098.95W

* All Stations from this point onward are part of the NCGP data set.

Table 1. (continued)

ID Number	Station Name	ID Letters	Latitude	Longitude
134	North Loup, NE	NENL	41.50N	098.77W
137	St. Paul, NE	NESP	41.20N	098.45W
126	Valentine, NE	NEVA	42.87N	100.55W
129	Wakefield, NE	NEWA	42.27N	096.87W
124	Academy, SD	SDAC	42.47N	099.08W
122	Clark, SD	SDCL	44.88N	097.73W
120	Faulkton, SD	SDFA	45.03N	099.13W
123	Forestburg, SD	SDFB	44.03N	098.03W
119	Milbank, SD	SDMB	45.22N	096.63W
118	Mellette, SD	SDME	45.15N	098.47W
125	Menno, SD	SDMN	43.23N	097.58W
121	Redfield, SD	SDRF	44.88N	098.38W

given for each station by decade for each variable in Appendix A. Figures 1a and 1b provide a pictoral representation of Table 1 and establish the distribution of stations used in this study. The stations in Nebraska and South Dakota are represented separately (Figure 1b) for readability.

b. Sources

There was a wide variety of sources for the monthly data included in the data base compiled as part of this study. Most of the 1951 to 1970 data were obtained in digitized form from The National Climatic Data Center (NCDC). About half the data prior to 1951 were extracted from microfiche, also from NCDC. Some data were taken from the Climatological Data books, U.S. Department of Agriculture (1914-1940); U.S. Department of Commerce (1940-1970). Most of the remaining data were obtained from their respective state climatologists, some in digitized form. NCDC provided microfiche of the Climate and Crop Report, U.S. Department of Agriculture (1900-1909), which were invaluable in filling in data prior to July, 1909. Most precipitation data were found in the Bulletin W, U.S. Department of Agriculture (1926, 1933); U.S. Department of Commerce (1955). The data were transferred from their various forms to a standardized format and missing data were estimated in the standard procedure given by the formulas below:

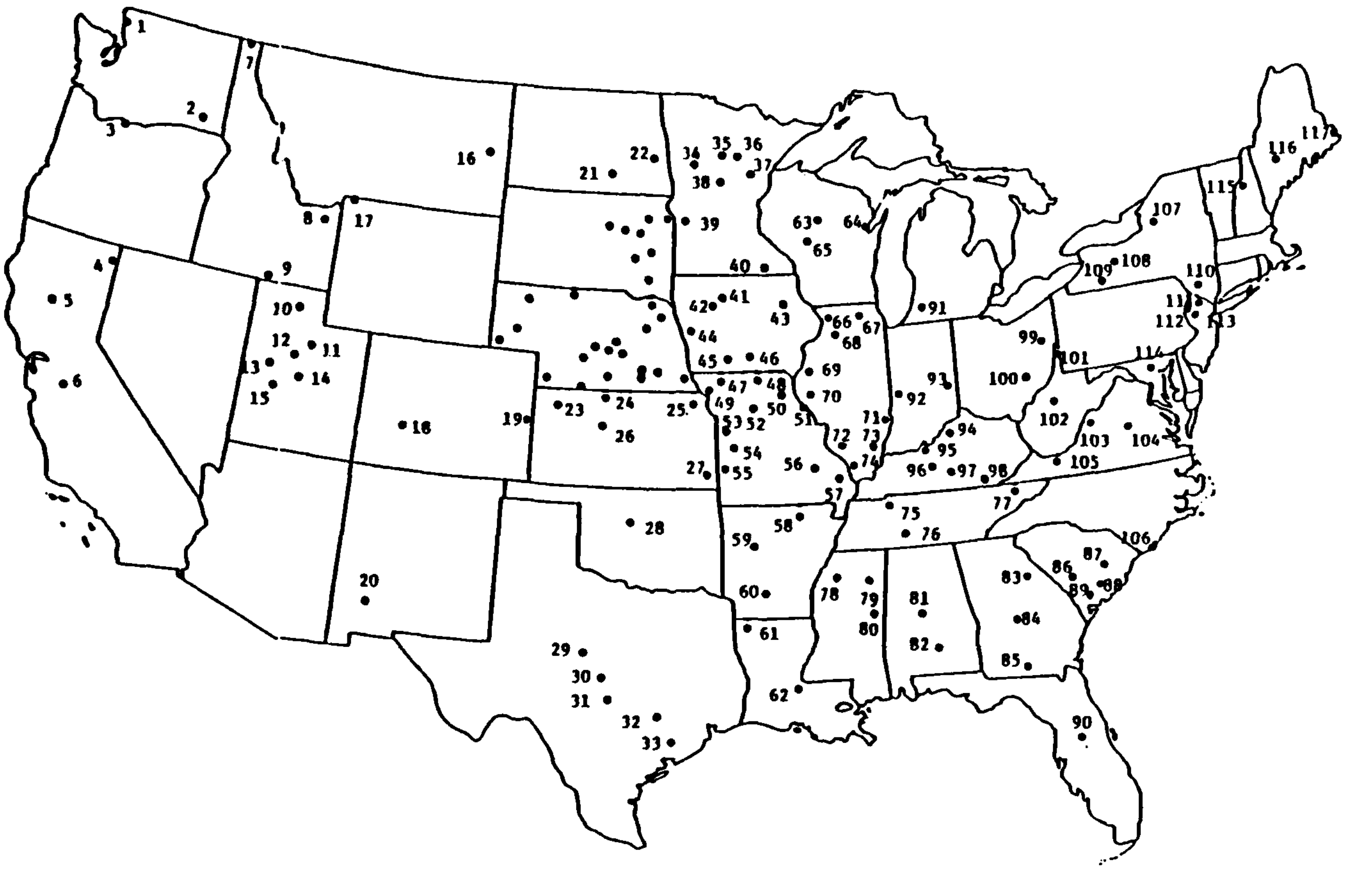


Figure 1a. U.S. Reference Stations. (See Table 1 for station names).

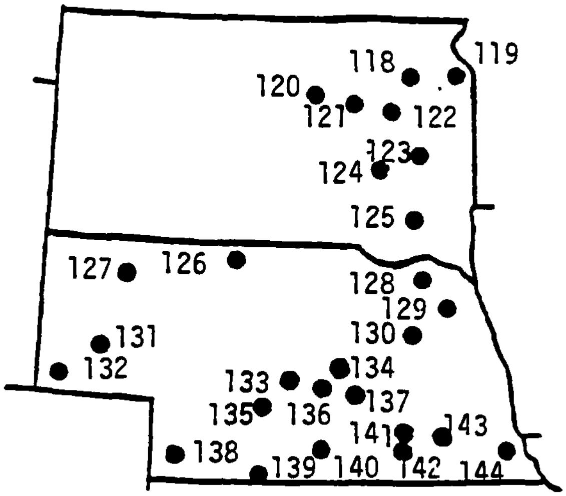


Figure 1b. Nebraska and South Dakota reference stations. (See Table 1 for station names).

$$E\ (\text{Temperature}) = \{(AC1 + AC2 + \ldots + ACk) - (NC1 + NC2 + \ldots + NCk)\}/2 + NS$$

$$E\ (\text{Precipitation}) = \{\{(AC1/NC1 + AC2/NC2 + \ldots + ACk/NCk)\}/k\} \cdot NS$$

where S = station for which datum is being estimated,

E = estimated value,

A = actual value,

N = normal value (30-year average),

C1 = comparison station one,

C2 = comparison station two, and

k = number of comparison stations.

The stations within a 30-mile radius of the reference station were used as comparison stations. As many as four comparison stations were used; in data-sparse areas the 30-mile limit was dropped and the nearest station was used for comparison. Temperature data for the period 1914 to 1970 for comparison stations were obtained from the Climatological Data books. For comparison station data between 1900 and 1913 the Monthly Weather Review, U.S. Department of Agriculture (1900-1913), Bulletin W, and The Report of the Chief of the Weather Bureau, U.S. Department of Agriculture (1900-1913) were used. The normals used for estimating were the 30-year averages available for the period closest to the missing month. Averages were obtained from the Bulletin W and from the monthly normals published in the Climatography of the United States No. 81, U.S. Department of Commerce (1973, 1982).

Table 2 indicates the reliability of the estimating procedure.

Table 2. Reliability of the estimating procedure. (Examples of how well estimates approximate actual observations.)

Geneva, NE	Actual[a]	Estimate
April Mean Maximum Temperature	68.7	69.0
April Mean Minimum Temperature	46.5	45.6
April Total Precipitation	2.94	4.34
Yemassee, SC	**Actual**	**Estimate**
July Mean Maximum Temperature	94.0	93.4
July Mean Minimum Temperature	73.0	70.7
July Total Precipitaion	9.62	9.44
Kingstree, SC	**Actual**	**Estimate**
February Mean Maximum Temperature	51.1	52.6
February Mean Minimum Temperature	30.9	37.6
February Total Precipitation	6.18	6.23

[a] Temperatures are in °F. Precipitation is in in.

Three estimates are presented for mean maximum, mean minimum and total monthly precipitation for randomly chosen stations which had available data. The estimates for minimum temperature seem to be the least accurate; this is probably due to local effects and the micro-climate nature of minimum temperature. Maximum temperature is a macroscale phenomenon which is very effectively estimated using the above formulas. Estimation of precipitation is much more likely to give spurious results than is estimation of temperature. Though each case presented here shows a very close agreement with the actual reported value, it is likely that precipitation estimates can be far less accurate than temperature estimates. Errors are inherent when dealing with the discontinuous field of precipitation, particularly in areas of convective precipitation; less error is expected when precipitation is occurring mainly as a result of frontal activity which is most frequently a winter phenomenon in the continental U.S.

c. Representation and Verification of Data

The time series for mean monthly maximum and minimum temperature and total precipitation composed the basic data set for this study. The data were reduced to winter (DJF), summer (JJA), and annual categories. Only December was used from the 1900 data; this was to complete the requirements for the winter 1901 data. A second representation of the temperature data was the difference from the 70-year mean; the relevant mean was subtracted from each observation for maximum and minimum temperature and retained as part of a separate series. In the same manner, precipitation was represented as the

percentage of its 70-year mean.

Partial verification of temperature data was accomplished by obtaining the differences between corresponding maximum (Tmax) and minimum (Tmin) temperatures for each station: any instances in which Tmax-Tmin was zero or a negative number were investigated and corrected. Precipitation was checked for accuracy by verifying and correcting, as necessary, all occurrences of precipitation 70% or more above or below the average over the period 1900-1970.

3. GROUPING OF CLIMATOLOGICAL DATA

a. Introduction

The North Central Great Plains (NCGP) of the United States is, from a geographical viewpoint, an almost ideally homogeneous region with a relatively dense data network. Data for this area were analyzed using various methods to determine an appropriate grouping procedure to apply to the U.S. data set. NCGP data are identified in Table 1, page 8. The objectives of the analysis of the NCGP were to:

1) determine regions with similar temperature and rainfall patterns;
2) combine data for stations within established regions to determine regional means; and
3) determine an analysis method to apply to the U.S. data set.

b. Grouping Methods

Cluster analysis was used initially to determine regions of the NCGP. Using raw data, as opposed to differences from the mean or percentages of the mean, the FASTCLUS procedure of the SAS System (SAS Institute, 1982) was invoked to perform the cluster analysis. FASTCLUS takes the first and second observations as its first 'seeds' and places the two observations in different clusters. All subsequent observations which are within half the distance between the seeds from the first or second observation are placed in the same cluster as the observation seed they are closer to. Any subsequent observations which are not close enough to the first two observations to meet the above condition are made seeds and new clusters are created. All

succeeding observations are tested against each seed and placed in appropriate clusters or are made seeds and a new cluster is created. FASTCLUS makes several passes through the data to minimize the number of clusters assigned.

The clustering procedure is dependent on the order of observations; for small data sets (less than several hundred observations) this could introduce bias in the clusters produced by the FASTCLUS procedure. The NCGP data set consists of 2730 observations (39 stations X 70 years), thus errors in cluster assignment due to ordering of the data were not expected. However, to test the clustering with a different order, a subset of 8 randomly chosen stations with 71-year records was clustered, then re-clustered after a random sort of the 568 (8 stations X 71 years) observations. The resulting clusters were the same and the cluster means were almost identical to the means of the first cluster procedure. The probability of error due to ordering was thus dismissed as negligible due to the large number of observations in the data sets under consideration, although the limitation for small data sets is noted.

Regions of the NCGP determined by cluster analysis are shown in Figures 2 and 3. It is apparent that the winter, summer and annual patterns for each element are dissimilar enough to warrant separate comparisons. Temperature maintains a latitudinal arrangement, but the precipitation pattern is almost exclusively longitudinal. In comparing different elements in the same season, minimum winter and maximum winter temperatures are similar; precipitation has a longitudinal pattern which is similar for all seasons. Minimum

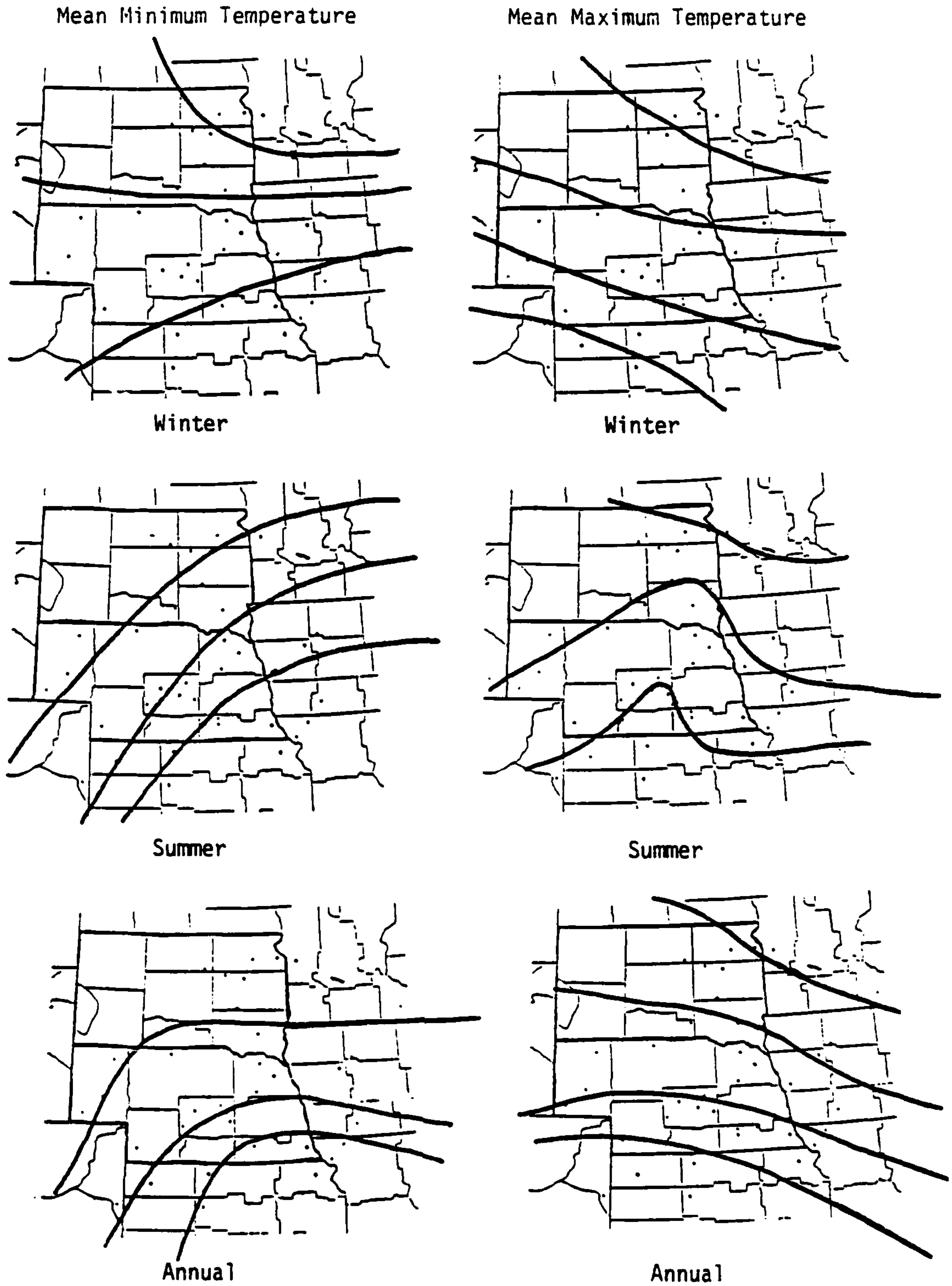
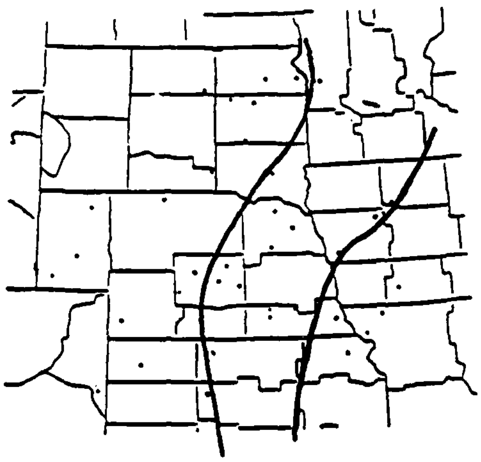
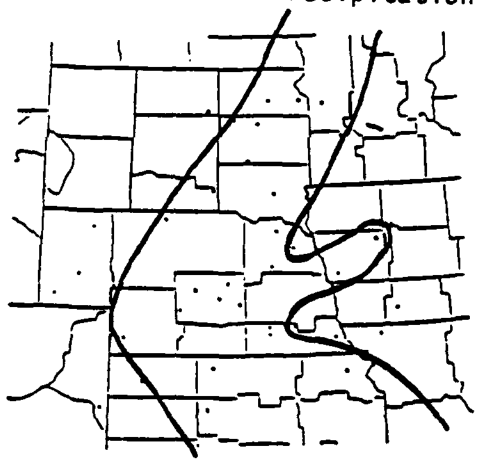


Figure 2. Regions of maximum and minimum temperature for the NCGP determined by cluster analysis.



Winter Total Precipitation

Annual Total Precipitation



Summer Total Precipitation

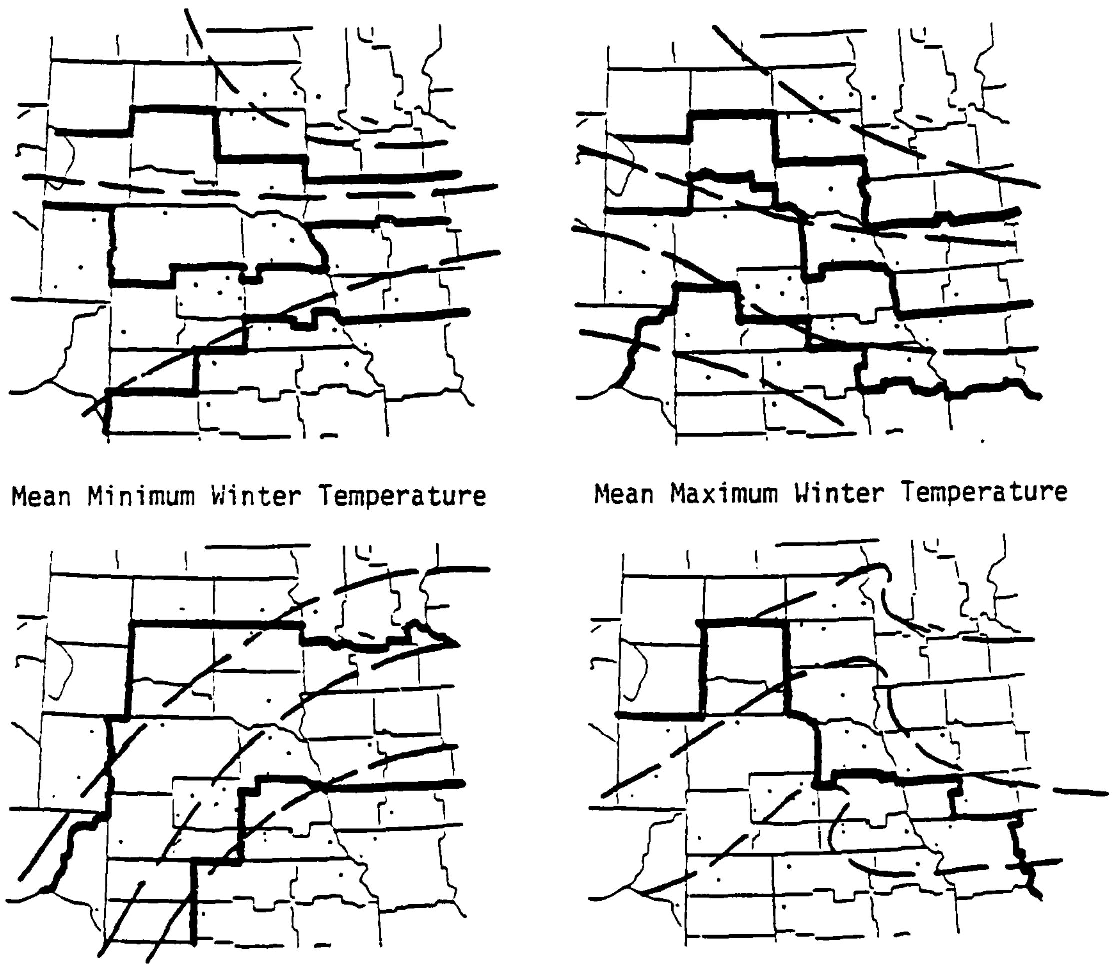
Figure 3. Regions of total precipitation for the NCGP determined by cluster analysis.

temperature has a much more longitudinal pattern for summer than it does for winter while maximum temperature remains latitudinal with perturbations toward a longitudinal pattern, particularly notable in summer.

A second method of grouping the NCGP data employed averaged climatological data for the NCGP area. The NCGP area was grouped by similar climatic division using the Climatic Atlas of the United States (U.S. Department of Commerce, 1968) based on 1931-1960 data. Climatic divisions were deemed 'similar' if warranted by patterns of isopleths of temperature or precipitation, as applicable, in the Climatic Atlas. The regions resulting from this climatological division method are shown in Figures 4 and 5. Regions previously determined by the cluster method are indicated by dashed lines. The two methods, clustering and climatological divisions, produce remarkably similar patterns.

The same cluster analysis previously discussed was applied to the NCGP data represented as differences from long-period means (for temperature) and percentage of long-period means (for precipitation). The results of cluster analysis applied to mean minimum temperature expressed as a difference from the long-period mean is shown in Figure 6a. The pattern is very different from the one seen in Figure 2 which was derived from raw data.

A final grouping method involved finding the overall mean of the NCGP and correlating individual stations to this overall mean. The results of this process for annual mean minimum temperature are shown in Figure 6b. Notice the much greater similarity of patterns between



Mean Minimum Winter Temperature

Mean Maximum Winter Temperature

Mean Minimum Summer Temperature

Mean Maximum Summer Temperature

Figure 4. Regions of mean minimum and mean maximum temperature for the NCGP determined from climatological division (solid lines) and from the cluster method (dashed lines).

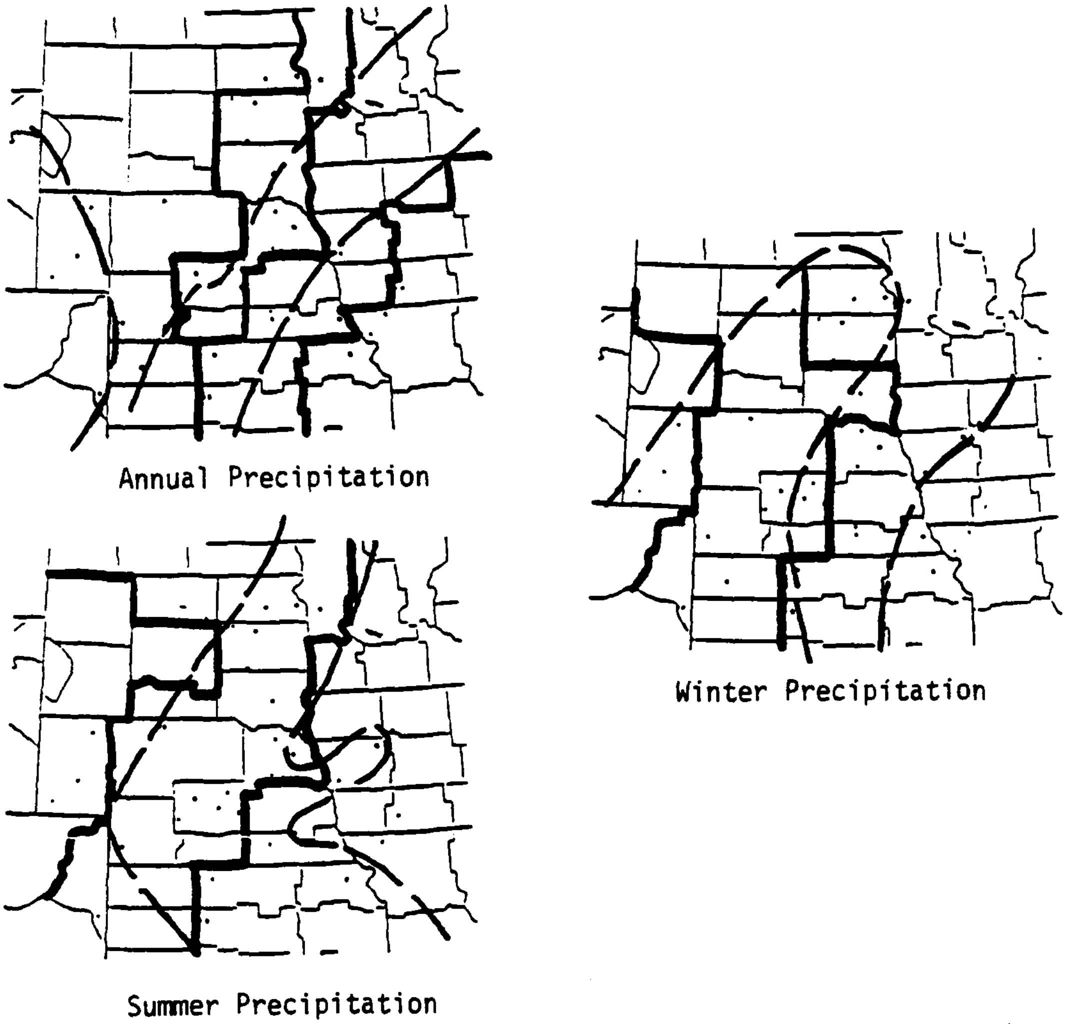
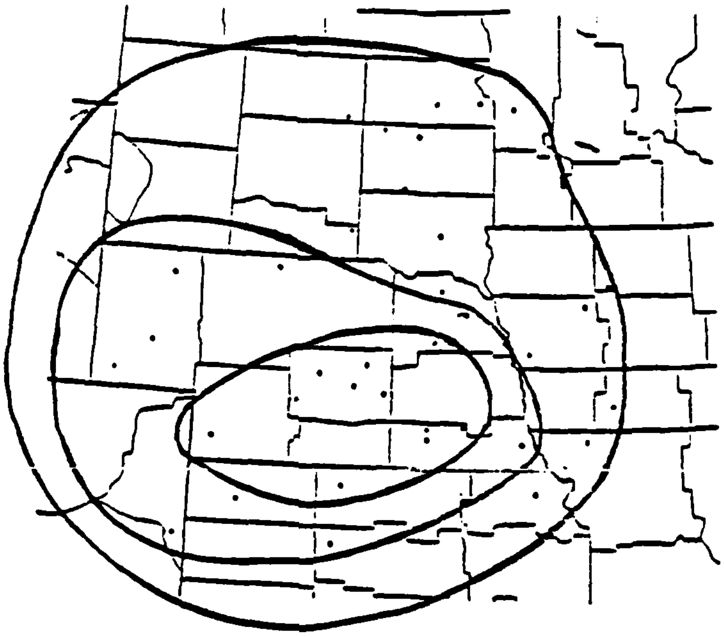
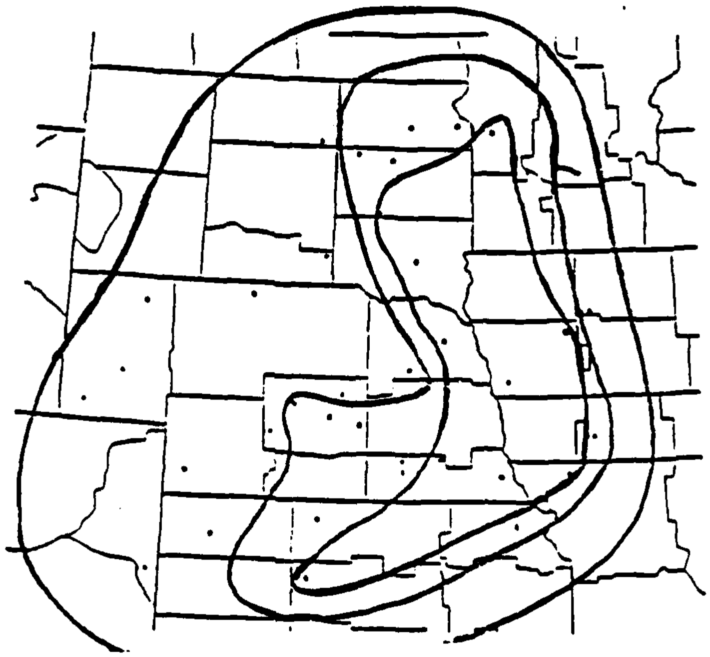


Figure 5. Regions of total precipitation for the NCGP determined from climatological division (solid lines) and from the cluster method (dashed lines).



(a)



(b)

Figure 6a. Regions of mean minimum temperature for the NCGP determined by cluster analysis using differenced data.

Figure 6b. Regions of mean minimum temperature for the NCGP determined by correlatin of differenced data.

the clustering using differenced data, Figure 6a, and the patterns derived from the correlation technique as opposed to clustering for raw and differenced data, Figure 6b.

c. Analysis of Grouping Methods

The original purpose of examining grouping methods was to determine which one would be most appropriate to use to divide the NCGP into coherent areas -- areas with similar temperature and precipitation patterns. The goal was to group the data in such a way as to reduce the error inherent in grouping data of stations with different weather patterns, such as has been done in the past using latitudinal zoning as a basis for grouping data. To test the effectiveness of the various grouping methods, a comparison of the overall standard errors of the means of the groups was made. Statistics for latitude band groupings were determined by dividing the NCGP area into a number of equal zonal areas; the number of areas was the same as the number of groups that had been determined by the cluster method. Standard errors of the means for the various groupings are shown in Table 3. The standard errors were derived from the following formula:

$$\text{standard error} = s/(N)^{1/2},$$

$$\text{where: } s^2 = \{\Sigma x_i^2 - N(\bar{x})^2\} / (N-1),$$

x_i = mean of region for year i,

$\bar{x}$ = overall 70-year mean for region, and

N = number of years (=70).

Inspection of Table 3 reveals that no method groups stations more

Table 3. Overall standard error of the mean associated with various groupings (°F).

Cluster	Latitude Band	Climatic Division
Mean Minimum Winter Temperature		
0.21	0.13	0.14
0.27	0.16	0.10
0.11	0.16	0.17
0.11	0.20	0.19
Mean Maximun Winter Temperature		
0.08	0.12	0.06
0.14	0.10	0.09
0.08	0.12	0.08
0.09	0.11	
Mean Minimum Annual Temperature		
0.06	0.13	0.05
0.07	0.09	0.04
0.08	0.07	0.08
0.08	0.09	

effectively than the simple latitude band method. The fact that none of the grouping methods applied to the NCGP data resulted in a better regional determination than did the zonal method implies that the NCGP is, in fact, homogeneous. Any of the groupings suggested by the various techniques described above is acceptable. However, some conclusions can be drawn as to meaning and applicability of the grouping techniques. Cluster analysis must be used discriminantly in studies of time series; clusters are determined only on the basis of which cluster the station fits the majority of the time. The cluster analysis technique provides that a station may fit in a cluster as little as 25% of the time and still be grouped with that cluster. It has been determined that the results of cluster analysis of raw data and determination of regions using climatic divisions are very similar. By the same token, cluster analysis of differenced data and grouping by correlation with the overall mean yield similar results. If the object of study deals with absolutes such as finding areas of hottest or coldest temperature, clustering of raw data will give the desired results. This investigation deals with analysis of climatic patterns. Analysis of patterns of weather elements is much better approached with the use of data which have their long-period means subtracted. Differenced data for climatic data stations can be compared and climatic patterns will emerge; the relativity that is lost when raw data are used then is preserved.

Based on the above discussion, there was a choice between use of the cluster method using differenced data and the correlation method for the analysis of the U.S. data. The method chosen for analysis of

the U.S. data was the correlation method; correlation provides a more readily determined quantifiable measure of the association between stations than does the cluster method. Appendix B includes the correlation coefficients resulting from correlation of each variable to the overall mean of the U.S. for that variable. Figures 7 and 8 show the regions of the U.S. for mean annual temperature and annual total precipitation, respectively, as defined by the correlation method. The regions described are compatible with mean air mass patterns over the U.S. The moderating influence of the Pacific and the Rocky Mountains as a barrier dictates a similar climate in the Western U.S. The North and South Rocky Mountain Regions are under the influence of similar air mass patterns in winter, but in summer the southern region is dominated by the southerly flow of dry air from Mexico and the arid southwest. The Rocky Mountain region was not readily distinguished as two groups when the correlation method of determining regions was applied to total annual precipitation, so it is considered one area for that variable. The Northeast and Southeast are under different air mass regimes due to their separate ocean influences. The North and Central regions exhibit very similar climate patterns although, of the two, the Northern region is under the influence of harsh continental arctic air to a much greater extent. Furthermore, air mass patterns of adjoining regions modify the patterns in the central region.

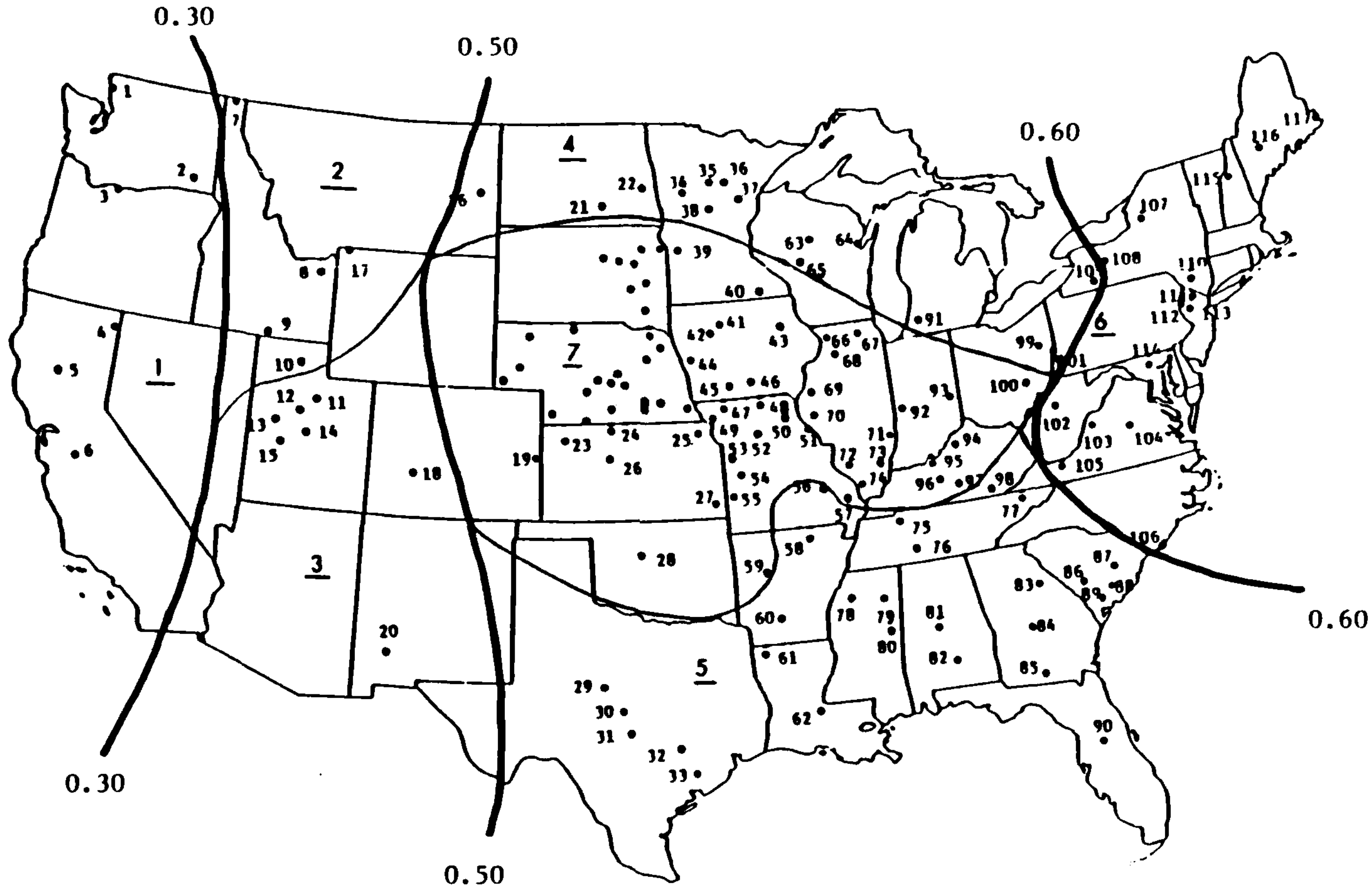


Figure 7. Regions of mean annual temperature for the U.S. as defined by the correlation method. Values of constant correlation (overall mean of 144 U.S. stations vs. individual stations) are provided in association with isopleths denoting regional boundaries. (Underlined numbers indicate region numbers which will be used in future references).

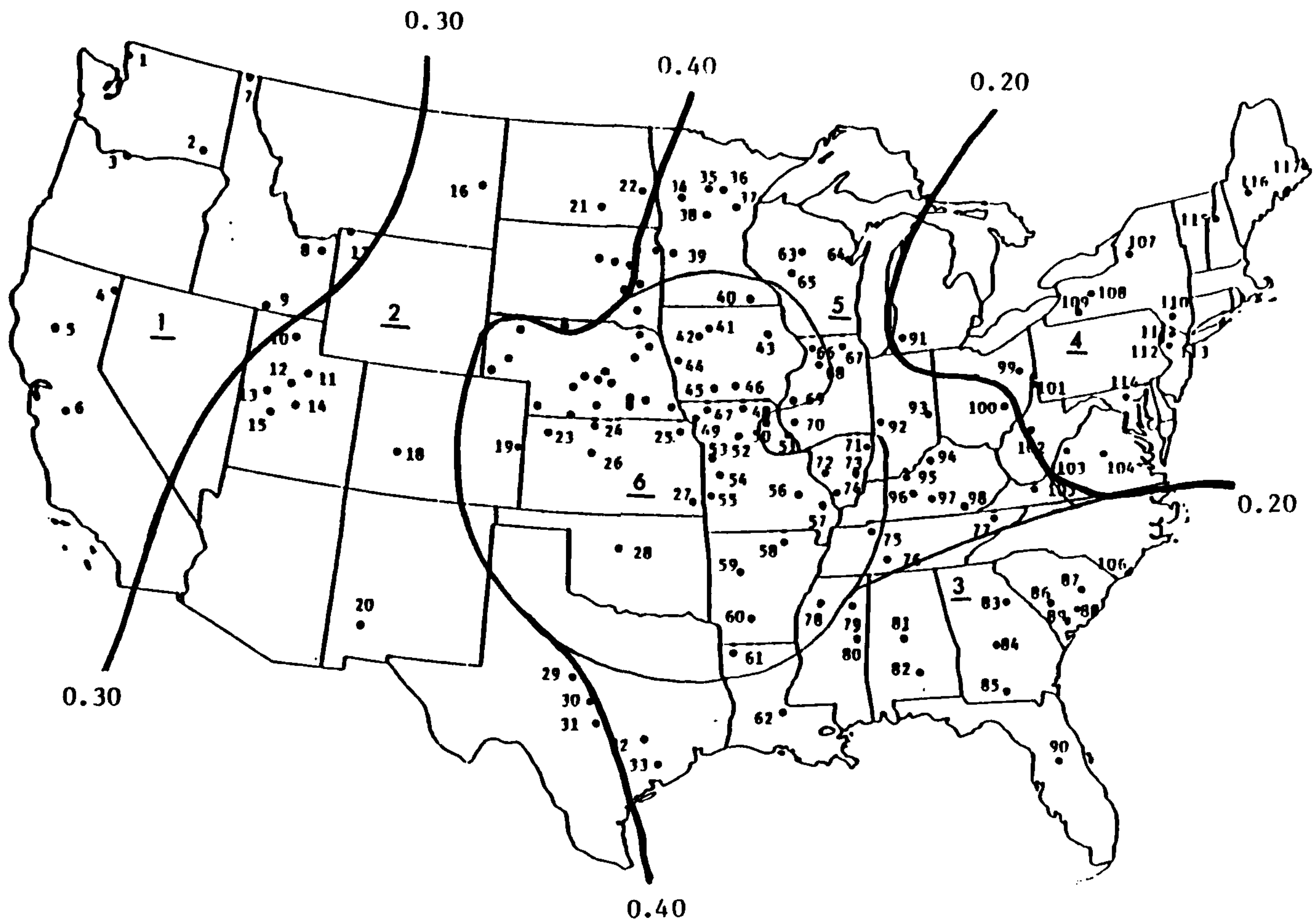


Figure 8. Regions of total annual precipitation for the U.S. as defined by the correlation method. Values of constant correlation (overall mean of 144 U.S. stations vs. individual stations) are provided in association with isopleths denoting regional boundaries. (Underlined numbers indicate region numbers which will be used in future references).

4. STATISTICAL METHODS

a. Tests of Normality

This study employs three statistical techniques for determination of normality of data: Cornu's test, the skewness test, and graphing data on "probability paper." Cornu's test (Brooks and Carruthers, 1953), is a test of normality which provides a determination of the relationship between the mean and standard deviation of a series. In a normally distributed series this relationship is given by $\sigma = 1.25 |e|$, where $|e|$, the mean deviation, is the summation of absolute values of deviations from the overall mean. The relation $|e|/\sigma = (2/\pi)^{1/2} = 0.80$ for normally distributed data is the basis for Cornu's criterion; Geary's (1935) limits for expected values of the ratio $|e|/\sigma$ for different numbers of observations are graphically depicted in Figure 9.

Cornu's criterion is a necessary, but not sufficient, condition for establishing the normality of a distribution. If, in addition to meeting Cornu's criterion, a series qualifies as normal under conditions of the skewness test, it can be considered not significantly different from a normal distribution. The skewness test requires that $\gamma = \mu_3/\sigma^3 < 2(6/N)^{1/2}$, for normally distributed data where μ_3 is the third moment, equal to the sum of the cubes of the deviations from the overall mean divided by the number of observations, and N is the number of observations in the series.

A simple method of determining if a distribution is approximately normal is to graph the series on "probability paper" (Brooks and Carruthers, 1953); use of this method cannot constitute proof of

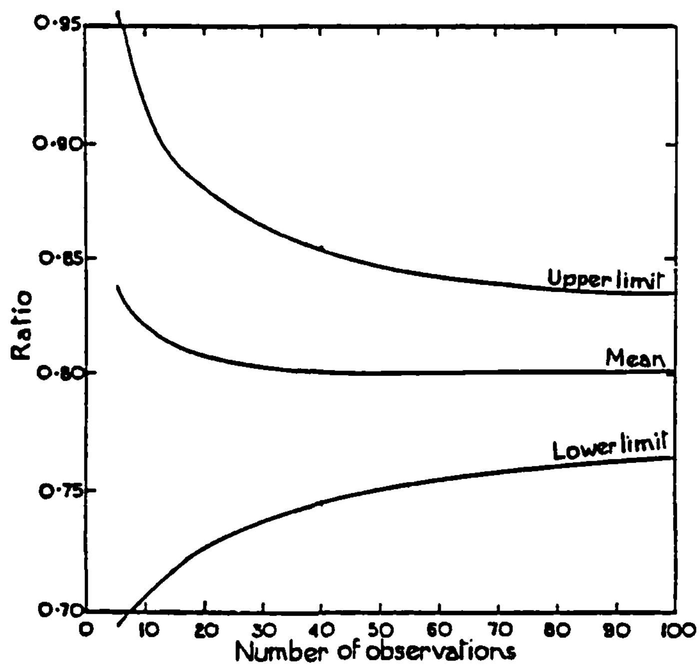


Figure 9. Average ratio, mean deviation/σ, and limits for 0.95 probability in a sample from a normal distribution (from Geary, 1935).

normality but does give an indication of whether or not a series is normal. The ordinate of a probability graph gives values of the probability integral, Appendix C, on a scale directly proportional to the corresponding normal deviate (x/σ). The following three steps are taken to plot a distribution on probability paper:

1. The N values of the variate are ranked and numbered according to the series 1/2, 3/2, 5/2, ... (N-1/2).
2. The numbers in the series from step 1 are divided by N to give a series approximating the probability integral for successive values of the variate, assuming normality.
3. Numbers from step 2 are plotted as ordinates against corresponding values of the variate as abscissa.

If the distribution is normal, or near normal, the points plotted in step 3 will closely resemble a straight line. The mean and standard deviation of the distribution can be estimated in the following manner: The mean is approximately equal to the value of the variate corresponding to the ordinate value of 0.50. The standard deviation is one-third of the difference between abscissa values corresponding to 0.067 and 0.933 (i.e., to 6.7 and 93.3%).

b. Tests of Homogeneity of Variance and Mean

If a series has been determined to consist of independent observations normally distributed about its mean, the Pearson-Hartley test of homogeneity of variance and the t-test of homogeneity of means can be applied to the series. The time series in this study are comprised of means of climatic elements based on non-overlapping one-

year periods; thus the series are considered independent which is a criterion for the Pearson-Hartley test. Some justification for consideration of normality was given before a test of homogeneity of variance or mean was conducted for any series.

The Pearson-Hartley test of homogeneity of variance, (Hart, 1942), is done by comparing the ratio s^2max/s^2min, where s^2max is the maximum and s^2min is the minimum variance observed in periods being tested with the value given in the Pearson-Hartley table, given here in Table 4. In this study, the 70-year series was divided into seven decades; thus the number of groups, k, being compared was seven and the degrees of freedom, γ, was nine.

Utilization of the t-test provided a measure of homogeneity of means among the decades discussed above. Two versions of the t-ratio are given below:

1. $t = (M_1 - M_2)\sigma\{(n_1 + n_2)/n_1 n_2\}^{1/2}$

2. $t = (M_1 - M_2)\{(n_1 + n_2 - 2)(n_1 n_2)/(n_1 + n_2)(n_1 s_1^2 + n_2 s_2^2)\}^{1/2}$

where M_1 = first sample mean,

M_2 = second sample mean,

n_1 = number of observations in first sample, and

n_2 = number of observations in second sample.

Expression 1 employs the standard deviation of the overall series which provides a better basis of comparison between all decades than does the use of variances between only the two decades under

Table 4. Percentage points of the ratio, s^2max/s^2min.

Upper 5% points

ν \ k	2	3	4	5	6	7	8	9	10	11	12
2	39·0	87·5	142	202	266	333	403	475	550	626	704
3	15·4	27·8	39·2	50·7	62·0	72·9	83·5	93·9	104	114	124
4	9·60	15·5	20·6	25·2	29·5	33·6	37·5	41·1	44·6	48·0	51·4
5	7·15	10·8	13·7	16·3	18·7	20·8	22·9	24·7	26·5	28·2	29·9
6	5·82	8·38	10·4	12·1	13·7	15·0	16·3	17·5	18·6	19·7	20·7
7	4·99	6·94	8·44	9·70	10·8	11·8	12·7	13·5	14·3	15·1	15·8
8	4·43	6·00	7·18	8·12	9·03	9·78	10·5	11·1	11·7	12·2	12·7
9	4·03	5·34	6·31	7·11	7·80	8·41	8·95	9·45	9·91	10·3	10·7
10	3·72	4·85	5·67	6·34	6·92	7·42	7·87	8·28	8·66	9·01	9·34
12	3·28	4·16	4·79	5·30	5·72	6·09	6·42	6·72	7·00	7·25	7·48
15	2·86	3·54	4·01	4·37	4·68	4·95	5·19	5·40	5·59	5·77	5·93
20	2·46	2·95	3·29	3·54	3·76	3·94	4·10	4·24	4·37	4·49	4·59
30	2·07	2·40	2·61	2·78	2·91	3·02	3·12	3·21	3·29	3·36	3·39
60	1·67	1·85	1·96	2·04	2·11	2·17	2·22	2·26	2·30	2·33	2·36
∞	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00

Upper 1% points

ν \ k	2	3	4	5	6	7	8	9	10	11	12
2	199	448	729	1036	1362	1705	2063	2432	2813	3204	3605
3	47·5	85	120	151	184	21(6)	24(9)	28(1)	31(0)	33(7)	36(1)
4	23·2	37	49	59	69	79	89	97	106	113	120
5	14·9	22	28	33	38	42	46	50	54	57	60
6	11·1	15·5	19·1	22	25	27	30	32	34	36	37
7	8·89	12·1	14·5	16·5	18·4	20	22	23	24	26	27
8	7·50	9·9	11·7	13·2	14·5	15·8	16·9	17·9	18·9	19·8	21
9	6·54	8·5	9·9	11·1	12·1	13·1	13·9	14·7	15·3	16·0	16·6
10	5·85	7·4	8·6	9·6	10·4	11·1	11·8	12·4	12·9	13·4	13·9
12	4·91	6·1	6·9	7·6	8·2	8·7	9·1	9·5	9·9	10·2	10·6
15	4·07	4·9	5·5	6·0	6·4	6·7	7·1	7·3	7·5	7·8	8·0
20	3·32	3·8	4·3	4·6	4·9	5·1	5·3	5·5	5·6	5·8	5·9
30	2·63	3·0	3·3	3·4	3·6	3·7	3·8	3·9	4·0	4·1	4·2
60	1·96	2·2	2·3	2·4	2·4	2·5	2·5	2·6	2·6	2·7	2·7
∞	1·00	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0

s^2_{max} is the largest and s^2_{min} the smallest in a set of k independent mean squares, each based on ν degrees of freedom.

Values in the column $k=2$ and in the rows $\nu=2$ and ∞ are exact. Elsewhere the third digit may be in error by a few units for the 5 % points and several units for the 1 % points. The third digit figures in brackets for $\nu=3$ are the most uncertain.

consideration, as expression 2 requires. Limits of significance are determined from the standard t-table, Appendix D, with degrees of freedom equal to $n_1 + n_2 - 2$.

c. Correlation Coefficients

The two types of correlation coefficients computed in this study were the Spearman rank correlation coefficient and the Pearson product-moment correlation coefficient. In all cases the two correlation coefficients determined were very similar. Formulas for both correlation coefficients are given below:

Spearman rank correlation coefficient

$$\rho = \frac{\Sigma(r_i - \bar{r})\ (q_i - \bar{q})}{\{\Sigma(r_i - \bar{r})^2\ \Sigma(q_i - \bar{q})^2\}^{1/2}}$$

Pearson product-moment correlation coefficient

$$r_{xy} = \frac{\Sigma(x_i - \bar{x})\ (y_i - \bar{y})}{\{\Sigma(x_i - \bar{x})^2\ \Sigma(y_i - \bar{y})^2\}^{1/2}}$$

where r = rank of the ith x value,

q = rank of ith y value, and

$\bar{r}$, $\bar{q}$ are means of the r and q values, respectively.

The Pearson product-moment correlation can be used to determine the scatter about the line of regression. This scatter is given by the relationship $s_{2,1} = s_2(1-r^2_{1,2})$, where $s_{2,1}$ = scatter about the regression line, s_2 = standard deviation of variable two, and $r_{1,2}$ = the correlation coefficient of the regression of variable one on variable two.

Transforming correlation coefficients through the Z transformation (Panofsky and Brier, 1968) provides a standardized

basis for comparison of those coefficients. If r= the correlation coefficient, $Z=1/2\{\ln(1+r)-\ln(1-r)\}$ is an approximately normal distribution with zero mean. Table 5 can be used to complete the Z transformation. The significance of correlations is judged by comparison of the F-ratio, $r^2(n-2)/(1-r^2)$, and F-table, Appendix E. When two series with different standard errors are correlated, the resultant regression line may not reflect the true association between the two series. Morgan (1960) addressed this topic and suggested a method to determine if the regression resulting from correlation of two such series would be affected by the difference in standard errors of the two series. Morgan's method was applied to two representative series in this study; the results indicated that the standard errors of temperature series and precipitation series are similar enough that the regression line would not be affected if any two temperature series or precipitation series were correlated.

d. Time Series Analysis

Mitchell (1966) provides a synopsis of his suggested methods for analysis of any climatological series:

a) verify homogeneity of the series,

b) establish the probable form of the frequency distribution of the variable under investigation,

c) compute the power spectrum,

d) determine if the series exhibits Markov persistence, and

e) test for statistically significant departures from the Markov spectrum.

Table 5. Conversion of r to Z.

$$Z = 1/2\ \{\log_e (1 + r) - \log_e (1 - r)\}$$

r	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.000	0.010	0.020	0.030	0.040	0.050	0.060	0.070	0.080	0.090
0.1	0.100	0.110	0.121	0.131	0.141	0.151	0.161	0.172	0.182	0.192
0.2	0.203	0.213	0.224	0.234	0.245	0.255	0.266	0.277	0.288	0.299
0.3	0.310	0.321	0.332	0.343	0.354	0.365	0.377	0.388	0.400	0.412
0.4	0.424	0.436	0.448	0.460	0.472	0.485	0.497	0.510	0.523	0.536
0.5	0.549	0.563	0.576	0.590	0.604	0.618	0.633	0.648	0.663	0.678
0.6	0.693	0.709	0.725	0.741	0.758	0.775	0.793	0.811	0.829	0.848
0.7	0.867	0.887	0.908	0.929	0.951	0.973	0.996	1.020	1.045	1.071
0.8	1.099	1.127	1.157	1.188	1.221	1.256	1.293	1.333	1.376	1.422
0.9	1.472	1.528	1.589	1.658	1.738	1.832	1.946	2.092	2.298	2.647

The data used in this study are assumed to be homogeneous because of the method of selection of the individual stations. Thus, the first step in analysis of the series is complete -- the data are homogeneous. Using a method similar to Mitchell's, the series of a random station was tested. Autoregression and spectral analysis of data were conducted by the Autoregressive Spectral Identification (ARSPID) program and the Multiple Spectral Density Estimation (MULTSP) program, Newton (1983). ARSPID is a univariate time series analysis program with multiple options for analysis and output. The program was applied to a representative temperature series, as explained in Appendix F. Results of the analysis indicated that the series was comprised of stochastic data. Since the series analyzed is representative of the other series under investigation, no further analysis of this type was performed on temperature data. Linear regression of the total annual precipitation series with time yielded approximately a horizontal line, indicating that precipitation series are linearly randomized data.

MULTSP is a bivariate analysis program which was used to test significance of errors in a temperature series resulting from observational difficulties. Mitchell (1953) presents a comprehensive study of temperature errors due to various causes, including measurement inaccuracies. The Highland Home, Alabama, monthly maximum temperatures 1900-1970 were adjusted to create two new series by adding amounts consistent with expected error of temperature measurements to the original series. The decimal value of each number in the series was adjusted to create a 'moderate' and 'extreme' series

as given in Table 6. The series were tested to determine if inclusion

Table 6. Moderate and extreme series additive factors.

Decimal value in original series	Additive factor moderate series	Additive factor extreme series
2, 4, 5	0	0
0, 1	+0.1	+0.2
3, 6	-0.1	-0.2
7	+0.2	+0.4
8	-0.2	-0.4
9	half +0.3	half +0.6
	half -0.3	half -0.6

of the error term would change the series to any significant extent. The moderate and extreme series were used as data in the MULTSP program to test for significant difference between the two series. Results of the bivariate analysis, explained in Appendix F, indicated that there was no significant difference between the two series. It is assumed that the same procedure applied to precipitation data would yield similar results; thus the error in temperature and precipitation series due to observational problems is considered insignificant.

Authors who have undertaken studies of climatological series have used a variety of filtering techniques to smooth their data. It is agreed that there is generally too much variability in the data points of a long climatic series to use the unfiltered series in most conventional approaches to analysis of those series. However, much information is lost by applying various smoothing techniques to the

data. The question of how to represent data in such a manner as to reduce the time required for analysis and yet retain enough original information in the data set is indeed a difficult one.

Mitchell (1966) has the following to say about moving averages applied to time series. ..."The acknowledged purpose of computing moving averages of a climatic time series is to smooth away the short (rapid) variations so that the longer (slower) variations can be revealed more clearly. If there are well-defined long-period variations in the series, this device can be quite helpful in revealing their form. If, however, the long-period variations are ill-defined - as they tend to be when the original series is an essentially random variation -- to emphasize them by means of moving averages can give the unwary analyst a false impression of their physical origin and nature."... Figure 10 reveals the effects of arbitrary smoothing for five-year and ten-year overlapping periods. It can be seen that there are several instances in which the smoothed data totally obscure the nature of the original series. Lawson et al. (1981) and Walsh et al.(1982) suggest analyzing separate areas with similar weather patterns. This is one way to retain original data in a statistical analysis; smaller groups of the large data set can be dealt with, thus allowing greater diversity in the overall data set. Any method of analysis, however, should be accompanied by a table or graph of the original data.

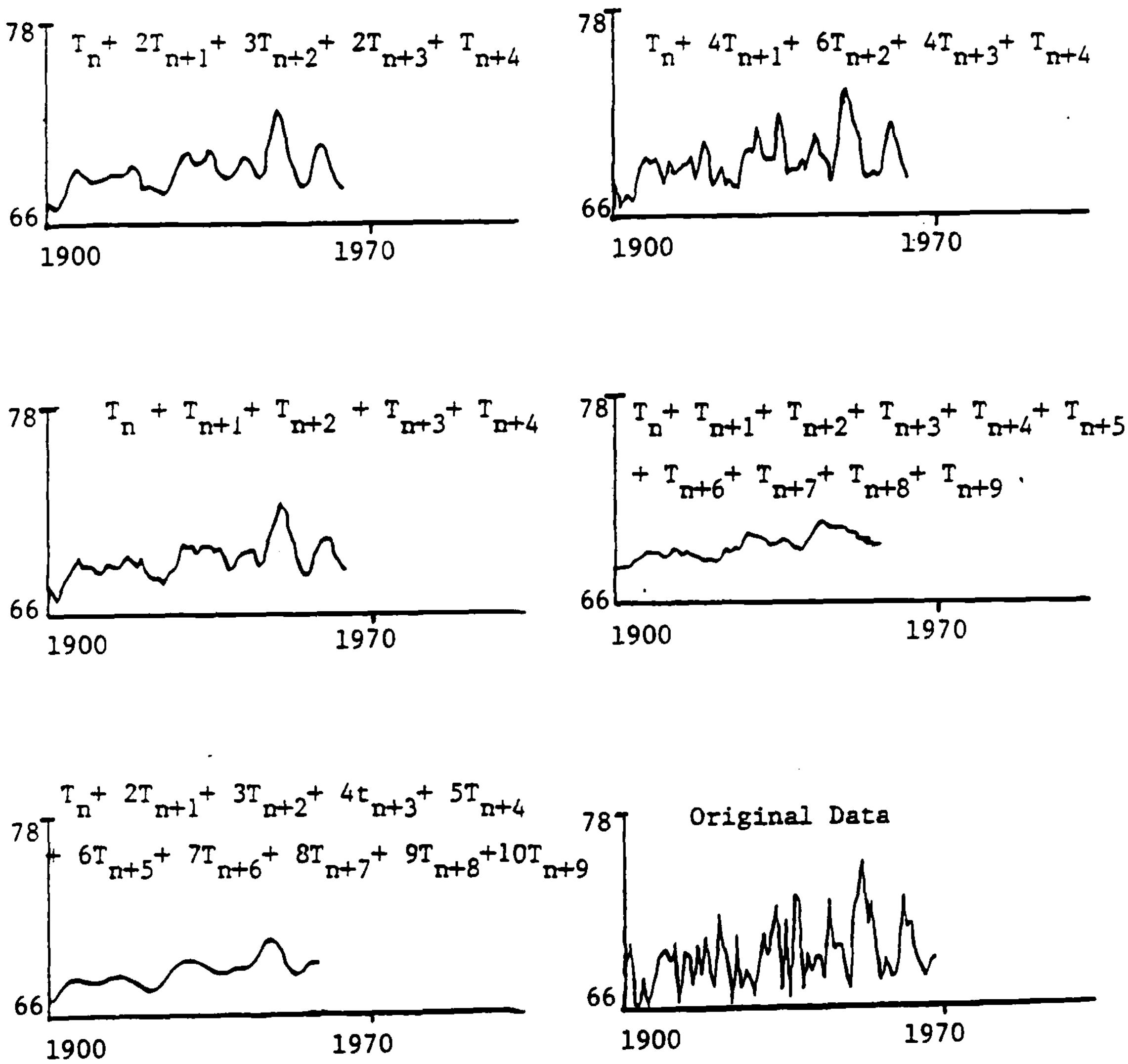


Figure 10. Various smoothings of mean maximum temperature for Columbus, KA (1900-1970). Abscissa = Year; Ordinate = Temperature in °F.

5. ANALYSIS

a. Analysis of North Central Great Plains Data

It has been established that the NCGP is a relatively homogeneous area; however, each station cannot represent the area equally well. Temperature and precipitation series for each station were compared with the overall mean series for the NCGP. The pattern of each element for each station is in close agreement with that of the overall mean for its respective element -- another indication that this is a relatively homogeneous area; however, there is less agreement with the overall mean in the SDAC, SDRF, and IARC series (see Table 1). The mean maximum temperature series for these stations were analyzed using a Spearman rank correlation. SDAC's correlation coefficient of 0.65 was lower than the 0.74 of SDRF and IARC. Assuming that the square of the rank correlation coefficient gives the amount of variation associated with the correlation between series, the lowest percentage of variation in the NCGP can be expected to be near 42%.

b. Analysis of U.S. Data

Data for the 144 U.S. stations utilized in this study were combined by season for each element to create twelve mean series, the data for which are given in Appendix G. Each series was tested for normality using the Cornu test and the skewness test before applying the Pearson-Hartley and t-tests for homogeneity of variance and mean, respectively. The results of these tests for each series are summarized in Table 7. All series with the exception of the annual

Table 7. Results of statistical tests on overall mean series. Txa=Max Annual Temp; Txw=Max Winter Temp; Txs=Max Summer Temp; Tna=Min Annual Temp; Tnw=Min Winter Temp; Tns=Min Summer Temp; Tma=Mean Annual Temp; Tmw=Mean Winter Temp; Tms=Mean Summer Temp; Pa=Total Annual Precip; Pw=Winter Precip; Ps=Summer Precip.

	Cornu 0.74-0.82+	Skewness <0.58+	Pearson-Hartley 0.05:8.41+ 0.01:13.10++	Decade with Max. Difference	t-test (1) 0.05:2.10+	t-test (2) 0.01:2.88++
Txa	0.78	0.58	6.15	4/1	3.65	2.28
Txw	0.80	0.54	6.55	6/2	2.30	1.60
Txs	0.78	0.29	5.40	4/1	3.76	2.69
Tna	0.72	0.20	13.22/3.00*	4/1,7	3.16	2.32
Tnw	0.77	0.35	7.95	4/7	2.46	1.59
Tns	0.80	0.23	4.57	4/1,7	4.04	3.13
Tma	0.74	0.43	8.90	4/1	3.79	2.42
Tmw	0.78	0.47	9.32	6/7	2.12	2.05
Tms	0.79	0.10	4.98	4/1	4.32	3.08
Pa	0.76	0.20	1.83	5/4	3.42	2.60
Pw	0.75	0.34	0.32	2/7	1.60	0.87
Ps	0.82	0.32	0.28	5/4	3.34	3.16

* s^2_{max}/s^2_{min} neglecting seventh decade (3.00)

+ values of the 0.05 significance level

++ values of the 0.01 significance level

underlined values are significant at the 0.05 level

minimum temperature were found to be normal. The minimum annual temperature series was subsequently graphed on "probability paper" as described in Section 4 a. The graph is given in Figure 11 and indicates that extreme values of minimum annual temperature approximate the normal distribution quite well; mid-ranked values do not deviate substantially from normal. Based on these results, the minimum annual temperature series was accepted as a normal distribution for the purposes of applying tests of homogeneity of variance and means.

The Pearson-Hartley and t-test of homogeneity of variance and mean, respectively, were applied to each series grouped by seven decades: 1901-1910, 1911-1920, 1921-1930,1931-1940, 1941-1950, 1951-1960, 1961-1970. An outline of decadal means and other simple statistics for each series is presented in Table 8.

The minimum annual temperature series showed exceptionally low variance in the last decade; the series failed the Pearson-Hartley test at the 0.05 level of significance. When the last decade was removed from consideration, the series was found to have homogeneous variance at the 0.01 level of significance.

The small variance in the seventh decade of the minimum annual temperature series is typical of the other temperature series; this fact is very interesting when considered in conjunction with proposals of increasing variability in temperature since 1960. Angell and Korshover (1978) advanced the concept of increasing variability of temperature based on a data set spanning the years 1958-1976. Van Loon and Williams (1978) and Diaz and Quayle (1980), among others,

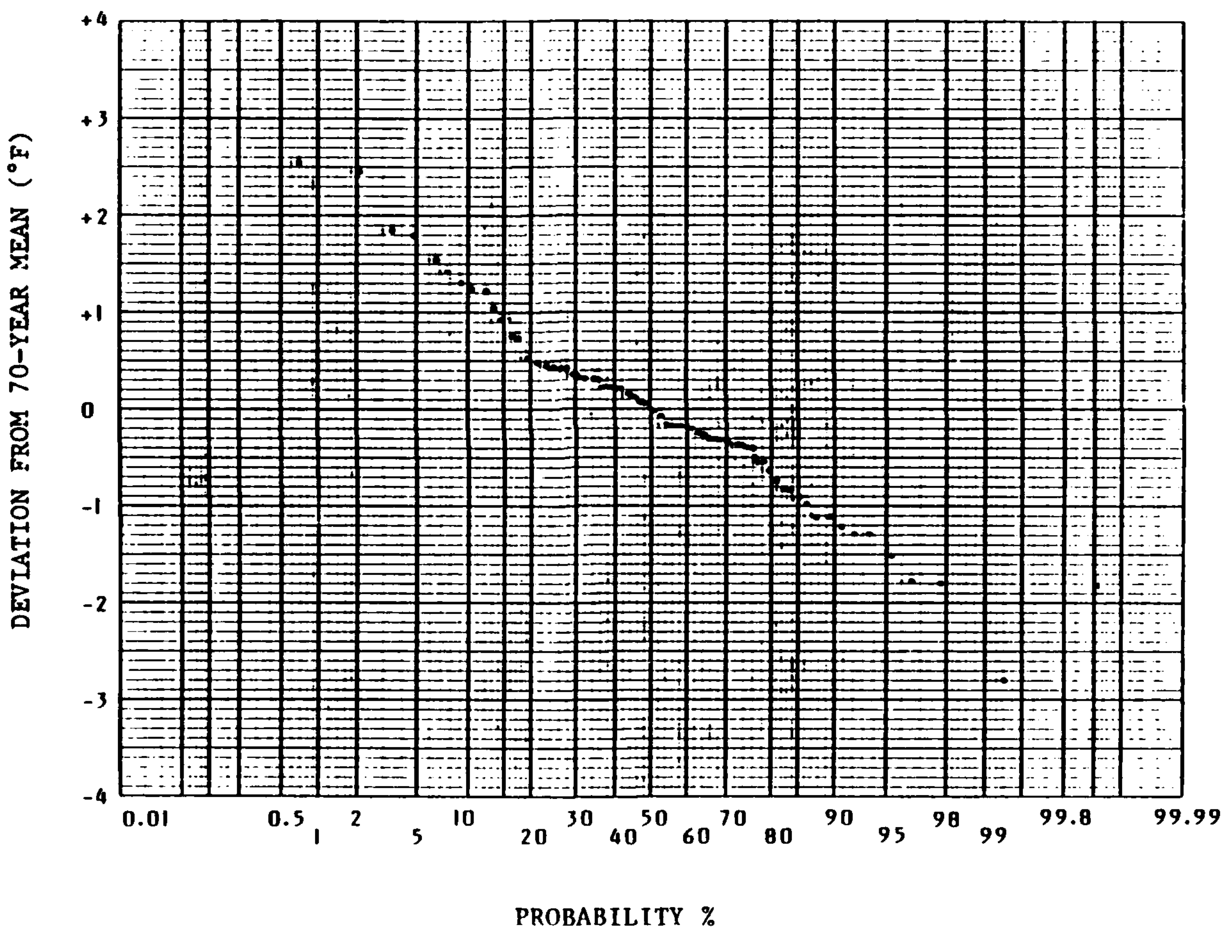


Figure 11. Minimum annual temperature plotted on normal probability paper.

Table 8. Simple statistics by decade for each mean series. (Temperatures are represented as deviations from their 70-year means)

Mean Series	Decade	Mean	Standard Deviation	Std Error of Mean	Variance
Annual Total Precipitation	1	33.53	3.00	0.95	9.01
	2	33.18	2.60	0.82	6.76
	3	32.91	2.33	0.74	5.42
	4	30.98	2.25	0.71	5.05
	5	34.50	1.96	0.62	3.84
	6	32.31	3.37	1.07	11.39
	7	32.92	2.34	0.74	5.47
Winter Precip	1	6.37	0.95	0.30	0.90
	2	6.31	0.98	0.31	0.96
	3	6.17	0.38	0.12	0.14
	4	6.32	1.42	0.45	2.03
	5	6.41	1.14	0.36	1.30
	6	6.22	0.56	0.18	0.31
	7	5.98	1.11	0.35	1.23
Summer Precip	1	10.98	1.02	0.32	1.05
	2	10.16	1.66	0.52	2.74
	3	10.18	1.55	0.49	2.41
	4	9.45	1.36	0.43	1.85
	5	10.95	0.50	0.16	0.25
	6	10.17	1.25	0.40	1.56
	7	10.43	0.68	0.22	0.47
Annual Temp	1	-0.62	0.67	0.21	0.45
	2	-0.57	0.99	0.31	0.98
	3	0.17	1.16	0.37	1.34
	4	1.00	1.16	0.37	1.34
	5	0.24	0.79	0.25	0.62
	6	0.23	0.98	0.31	0.97
	7	-0.47	0.38	0.12	0.15
Winter Temp	1	-1.11	2.60	0.82	6.75
	2	-1.08	2.28	0.72	5.20
	3	0.69	1.81	0.57	3.26
	4	0.92	3.01	0.95	9.04
	5	0.70	1.05	0.33	1.09
	6	0.95	1.77	0.56	3.12
	7	-1.12	0.98	0.31	0.97
Summer Temp	1	-0.90	1.27	0.40	1.61
	2	-0.38	1.48	0.46	2.14
	3	-0.24	1.16	0.37	1.35
	4	1.66	1.08	0.34	1.16
	5	-0.10	1.10	0.35	1.20
	6	0.42	0.99	0.31	0.99
	7	-0.43	0.65	0.21	0.43

Table 8. (cont)

Mean Series	Decade	Mean	Standard Deviation	Std Error of Mean	Variance
Ann Max Temp	1	-0.73	0.80	0.25	0.64
	2	-0.70	1.01	0.32	1.02
	3	0.12	1.21	0.38	1.46
	4	1.15	1.44	0.46	2.09
	5	0.18	0.80	0.25	0.63
	6	0.34	1.25	0.40	1.57
	7	-0.41	0.58	0.18	0.34
Winter Max T	1	-1.21	2.60	0.82	6.76
	2	-1.23	2.15	0.68	4.62
	3	0.68	1.60	0.51	2.55
	4	0.75	3.15	0.99	9.89
	5	0.77	1.26	0.40	1.59
	6	1.04	1.85	0.58	3.42
	7	-0.82	1.23	0.39	1.51
Summer Max T	1	-1.16	1.53	0.48	2.34
	2	-0.38	1.87	0.59	3.51
	3	-0.23	1.45	0.46	2.09
	4	2.09	1.58	0.50	2.49
	5	-0.31	1.17	0.37	1.37
	6	0.43	1.32	0.42	1.74
	7	-0.60	0.81	0.26	0.65
Ann Min Temp	1	-0.49	0.63	0.20	0.40
	2	-0.42	1.04	0.33	1.08
	3	0.22	1.09	0.35	1.19
	4	0.82	0.94	0.30	0.88
	5	0.28	0.86	0.27	0.74
	6	0.12	0.76	0.24	0.58
	7	-0.49	0.31	0.10	0.09
Winter Min T	1	-1.00	2.63	0.83	6.93
	2	-0.94	2.58	0.82	6.64
	3	0.71	1.97	0.62	3.88
	4	1.10	2.96	0.94	8.75
	5	0.66	1.13	0.36	1.28
	6	0.89	1.84	0.58	3.38
	7	-1.40	1.05	0.33	1.10
Summer Min T	1	-0.68	1.06	0.34	1.13
	2	-0.40	1.13	0.36	1.28
	3	-0.28	1.05	0.33	1.11
	4	1.22	0.58	0.18	0.34
	5	0.08	1.07	0.34	1.15
	6	0.40	0.69	0.22	0.48
	7	-0.33	0.53	0.17	0.28

Table 8. (cont)

Mean Series	Decade	Mean	Standard Deviation	Std Error of Mean	Variance
Ann Max Temp	1	-0.73	0.80	0.25	0.64
	2	-0.70	1.01	0.32	1.02
	3	0.12	1.21	0.38	1.46
	4	1.15	1.44	0.46	2.09
	5	0.18	0.80	0.25	0.63
	6	0.34	1.25	0.40	1.57
	7	-0.41	0.58	0.18	0.34
Winter Max T	1	-1.21	2.60	0.82	6.76
	2	-1.23	2.15	0.68	4.62
	3	0.68	1.60	0.51	2.55
	4	0.75	3.15	0.99	9.89
	5	0.77	1.26	0.40	1.59
	6	1.04	1.85	0.58	3.42
	7	-0.82	1.23	0.39	1.51
Summer Max T	1	-1.16	1.53	0.48	2.34
	2	-0.38	1.87	0.59	3.51
	3	-0.23	1.45	0.46	2.09
	4	2.09	1.58	0.50	2.49
	5	-0.31	1.17	0.37	1.37
	6	0.43	1.32	0.42	1.74
	7	-0.60	0.81	0.26	0.65
Ann Min Temp	1	-0.49	0.63	0.20	0.40
	2	-0.42	1.04	0.33	1.08
	3	0.22	1.09	0.35	1.19
	4	0.82	0.94	0.30	0.88
	5	0.28	0.86	0.27	0.74
	6	0.12	0.76	0.24	0.58
	7	-0.49	0.31	0.10	0.09
Winter Min T	1	-1.00	2.63	0.83	6.93
	2	-0.94	2.58	0.82	6.64
	3	0.71	1.97	0.62	3.88
	4	1.10	2.96	0.94	8.75
	5	0.66	1.13	0.36	1.28
	6	0.89	1.84	0.58	3.38
	7	-1.40	1.05	0.33	1.10
Summer Min T	1	-0.68	1.06	0.34	1.13
	2	-0.40	1.13	0.36	1.28
	3	-0.28	1.05	0.33	1.11
	4	1.22	0.58	0.18	0.34
	5	0.08	1.07	0.34	1.15
	6	0.40	0.69	0.22	0.48
	7	-0.33	0.53	0.17	0.28

have shown that temperature variability increased from approximately 1900 to 1940 and decreased from about 1940 to 1975. Table 8 indicates that this study reveals the same pattern of variability; thus statements that the variability of temperature in the north temperate latitudes in recent years has been increasing should be prefaced with the fact that current variablity is less than the long-term average variability.

A detailed synopsis of the results of the t-test applied to each series is given in Table 9. When seven pairs of decades are compared for each of twelve elements, the number of pairs of decades found to have significantly different mean at the 0.01 level of significance is expected to be on the order of three (12x21/100); Table 9 contains more than four times the expected number. Decades one and four of each summer and mean temperature series exhibit significantly different means. In every temperature series other than the minimum winter and mean winter series, the mean in the fourth decade is higher than for any other decade and the mean in the first decade is the lowest observed for any decade. Annual and summer precipitation show higher means when temperature is low and lower means when temperature is high. The fourth and fifth decades of the annual and summer precipitation series are significantly different; the fourth decade in both of these series has a lower mean than any other decade. The correlation of each variable versus all others is given in Appendix H. As previously intimated, precipitation and temperature are usually negatively correlated.

c. Analysis of Grouped and Area-Weighted U.S. Data

Table 9. t-ratios of orverall mean series. Txa=Max Annual Temp; Txw=Max Winter Temp; Txs=Max Summer Temp; Tna=Min Annual Temp; Tnw=Min Winter Temp; Tns=Min Summer Temp; Tma=Mean Annual Temp; Tmw=Mean Winter Temp; Tms=Mean Summer Temp; Pa=Total Annual Precip; Pw=Winter Precip; Ps=Summer Precip.

t-ratios* for extreme and significant decades

	Dec	t-ratio	Dec	t-ratio	Dec	t-ratio	Dec	t-ratio	Dec	t-ratio
Txa	4/1	<u>3.65</u>	4/2	<u>3.59</u>	4/7	<u>3.03</u>				
Txw	6/2	2.30	6/1	2.28						
Txs	4/1	<u>3.76</u>	4/7	<u>3.60</u>	4/2	<u>3.30</u>	4/5	<u>3.21</u>	4/3	<u>3.10</u>
Tna	4/1	<u>3.16</u>	4/2	<u>2.99</u>						
Tnw	4/7	2.46	6/7	2.26	4/6	<u>3.29</u>	4/3	<u>3.19</u>	4/5	2.42
Tns	4/1	<u>4.04</u>	4/2	<u>3.44</u>	4/7	<u>3.29</u>	4/3	<u>3.19</u>	6/1	2.29
Tma	4/1	<u>3.79</u>	4/2	<u>3.50</u>	4/7	<u>3.27</u>				
Tmw	6/7	2.12								
Tms	4/1	<u>4.32</u>	4/7	<u>3.53</u>	4/2	<u>3.44</u>	4/3	<u>3.20</u>	4/5	<u>2.97</u>
Pa	5/4	<u>3.42</u>	5/1	<u>2.90</u>	2/4	2.36	2/7	2.36		
Pw	2/7	1.60								
Ps	5/4	<u>3.34</u>	1/4	<u>2.94</u>	7/4	2.74				

* t-ratio required for significance at 0.05 level≥2.10
at 0.01 level≥2.88

values underlined are significant at the 0.01 level

Regions determined from the correlation method described in Sections 3b and 3c above were area-weighted and new overall U.S. mean annual temperature and annual total precipitation series were determined. Appendix I includes graphs and data for the regional series and data for the original and area-weighted mean series; Figures 12a and b and 13a and b give the graphs of the overall and weighted overall mean annual temperature and annual total precipitation series.

The overall annual mean temperature of 52.34°F was altered only slightly to 52.51°F when area-weighting was applied to the data; however, the average range in annual differences between the original and weighted series was over 1°F, indicating variable contributions by regions.

Annual total precipitation showed consistently greater amounts in the original mean series versus values in the weighted series. The differences of the two series were normally distributed around a mean of 3.53 in. with a maximum difference of 5.32 and minimum difference of 1.32 in.. The substantial difference in the arithmetic mean and weighted mean precipitation for the U.S. demonstrates that considerable variability of results can be expected when the same data are analyzed using different methods. For example, the western U.S. is obviously drier than the rest of the country; this fact contributes substantially to a difference in the arithmetic and area-weighted series.

There are noticeable differences between regional mean annual temperature series, given in Appendix I, and the overall mean annual

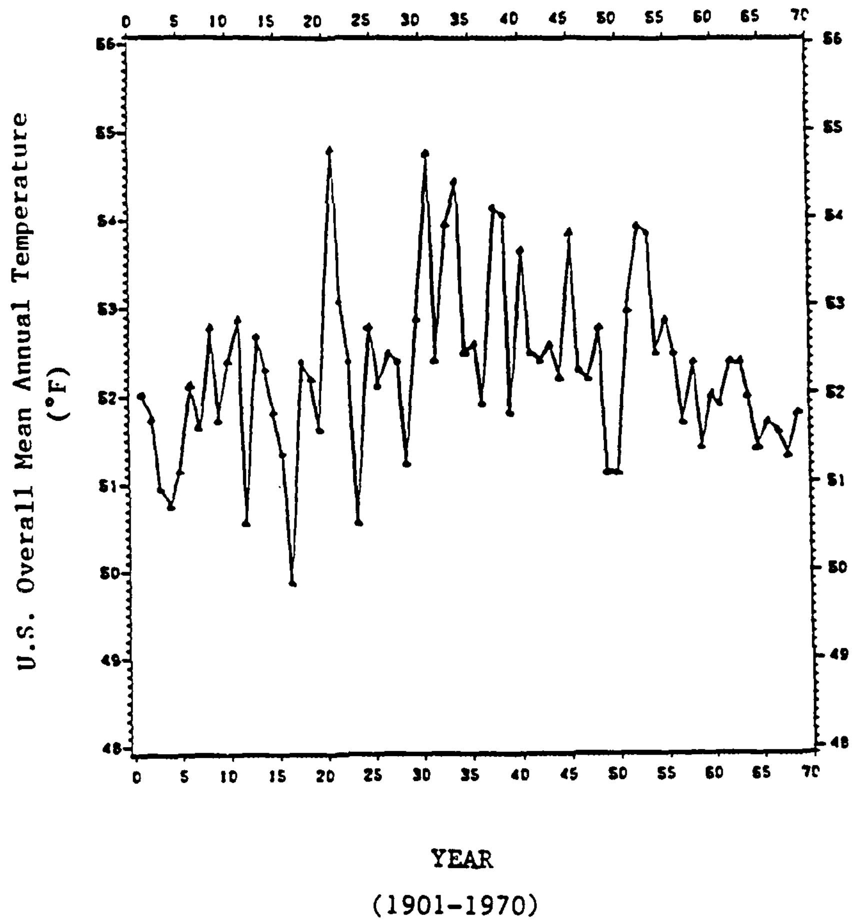


Figure 12a. Overall mean annual temperature for 144 U.S. stations.

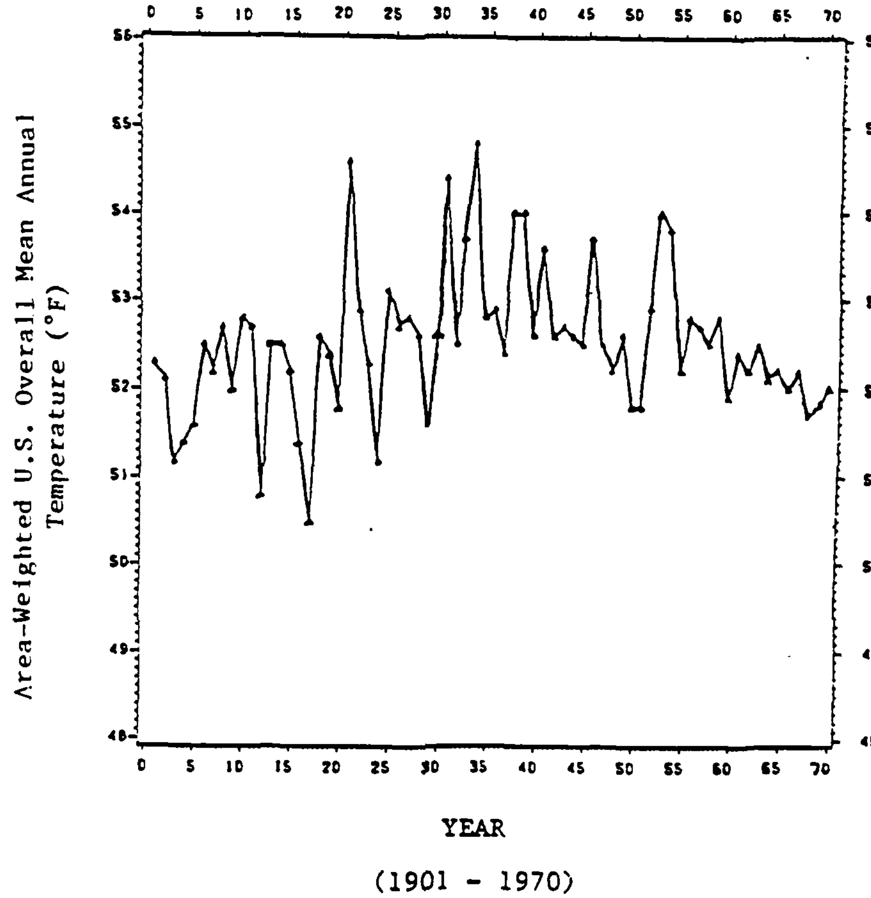


Figure 12b. Areally-weighted mean annual temperature for 144 U.S. stations.

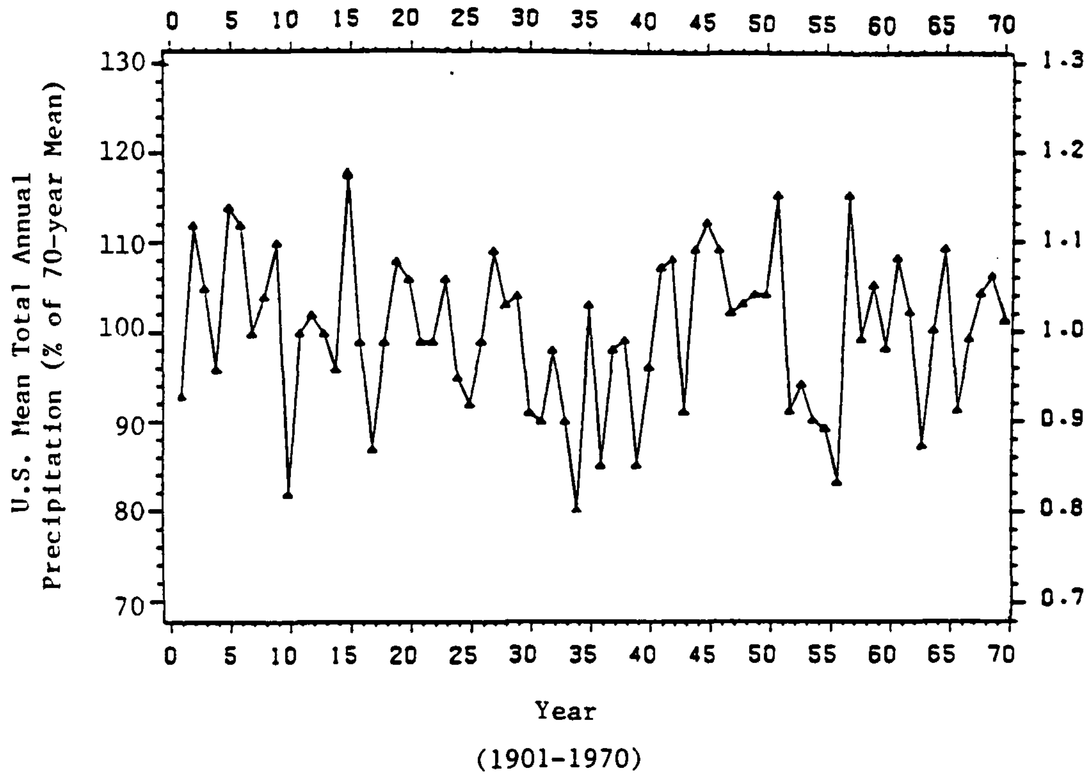


Figure 13a. Percentage of 70-year U.S. total mean annual precipitation 1901-1970.

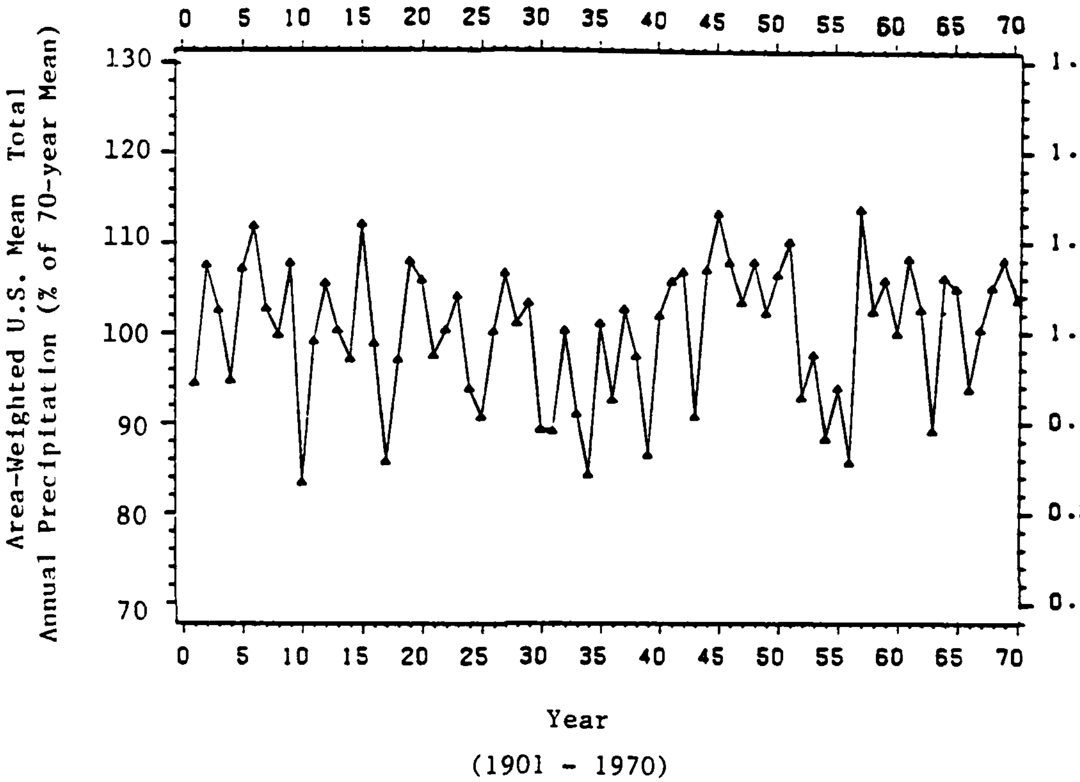


Figure 13b. Percentage of area-weighted 70-year U.S. total mean annual precipitation 1901-1970.

temperature series. Appendix J gives a breakdown of simple statistics, by decade, for the regional mean annual temperature and total precipitation series; different regions display varying patterns of means of temperature and precipitation in different decades. Thus, there is substantial reason to analyze individual regions as opposed to the entire U.S. when investigating temperature trends. The correlation coefficients of mean annual temperature and total annual precipitation for each region and the overall mean are given in Table 10. It should be noted that the correlation coefficients for each region versus the overall mean are of dubious reliability since the regional and overall mean series are not independent. The high correlations of regions 1, 2, and 3 compared with the other regions indicates that comparison of temperature data should at the very least be analyzed with respect to the area West of the Rockies and to the area East of the Rockies to avoid the resultant cancelling of data that will occur when areas following opposite patterns are combined.

In the case of precipitation, the correlations are low except between regions 5 and 6. Thus, any grouping of data between regions will degrade the integrity of the various regional data sets.

Willett's arithmetic average method and Mitchell's area-weighting both yield similar results when applied to the 144 U.S. stations used in this study. There exist numerous methods to group data; however, it is doubtful that any logical method would produce a significant difference in the weighted and arithmetic means of temperature. Regions may not be representative of the true climatic patterns of their areas, primarily due to sparsity of data and lack of

Table 10.

Part I Pearson correlation coefficients of mean annual temperature for each region of similar temperature versus each of the other regions and the overall mean.

	Region							
Region	1	2	3	4	5	6	7	Mean
1	1.00							
2	0.74	1.00						
3	0.55	0.78	1.00					
4	0.09	0.32	0.19	1.00				
5	-0.09	-0.02	0.21	0.39	1.00			
6	-0.13	-0.11	0.04	0.65	0.70	1.00		
7	0.20	0.40	0.41	0.82	0.65	0.61	1.00	
Mean	0.22	0.38	0.43	0.82	0.74	0.71	0.98	1.00

Part II Pearson correlation coefficients of total annual precipitation for each region of similar precipitation versus each of the other regions and the overall mean.

	Region						
Region	1	2	3	4	5	6	Mean
1	1.00						
2	0.18	1.00					
3	-0.05	0.33	1.00				
4	0.27	-0.14	0.01	1.00			
5	0.30	0.45	0.20	0.35	1.00		
6	0.14	0.58	0.20	0.18	0.71	1.00	
Mean	0.28	0.64	0.44	0.35	0.83	0.92	1.00

+ > 0.255, P < 0.05
+ > 0.306, P < 0.01

geographical similarity within regions. A case in point is region 2, representing 14% of the U.S. for mean temperature. This region contains parts of seven states, yet only three states are represented with data, and one state provides over 70% of the data in the region. A comparison of temperature and precipitation series of individual stations to their respective regional series was accomplished to determine how well individual stations represented the mean of the region. Stations whose correlation coefficients from the original grouping procedure (see Appendix B) were least compatible with other stations within their region were chosen for inspection. Figures 14a-g contain the individual series of mean annual temperature and total precipitation for those stations which were least representative of their regions. Comparison of the individual series with their respective regional series (Appendix I) reveals some definite contradictions of patterns between regions and stations comprising those regions. Stations can show marked variations of weather from year to year. A station may exhibit characteristics of its neighboring stations to the west one year and then have weather more compatible with its northern neighbors the following year. Weather systems on the synoptic scale change from year to year as well as from week to week; weather at an individual station is the reflection of synoptic scale changes and local effects. Thus, it must be understood that while the regional boundaries discussed above offer a simplified way of analyzing climatic data, some stations within certain regional boundaries may experience weather much unlike that of their regional counterparts. Diaz and Quayle (1980) produced a study of U.S. mean

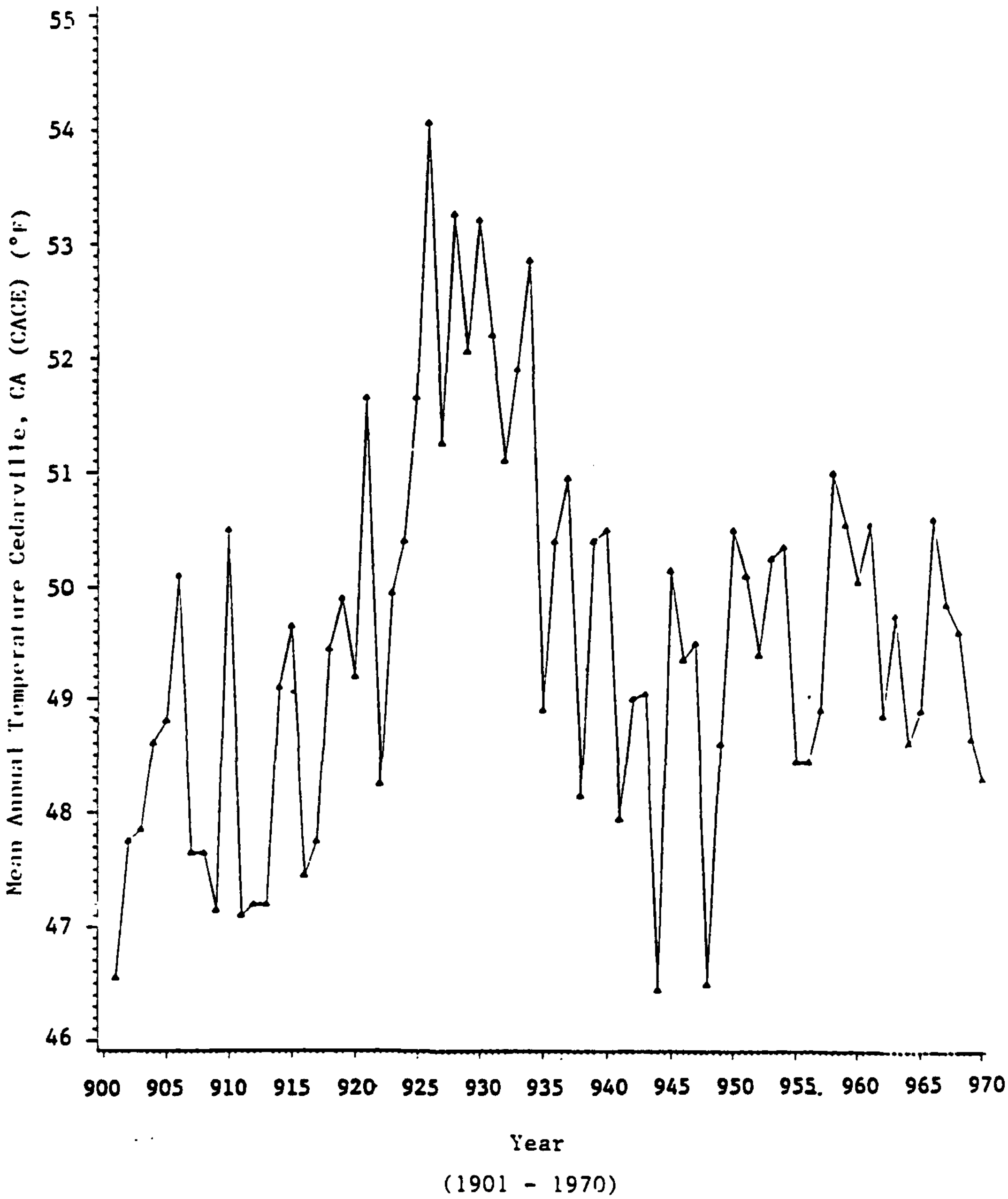


Figure 14a. Mean annual temperature for CACE 1901-1970.

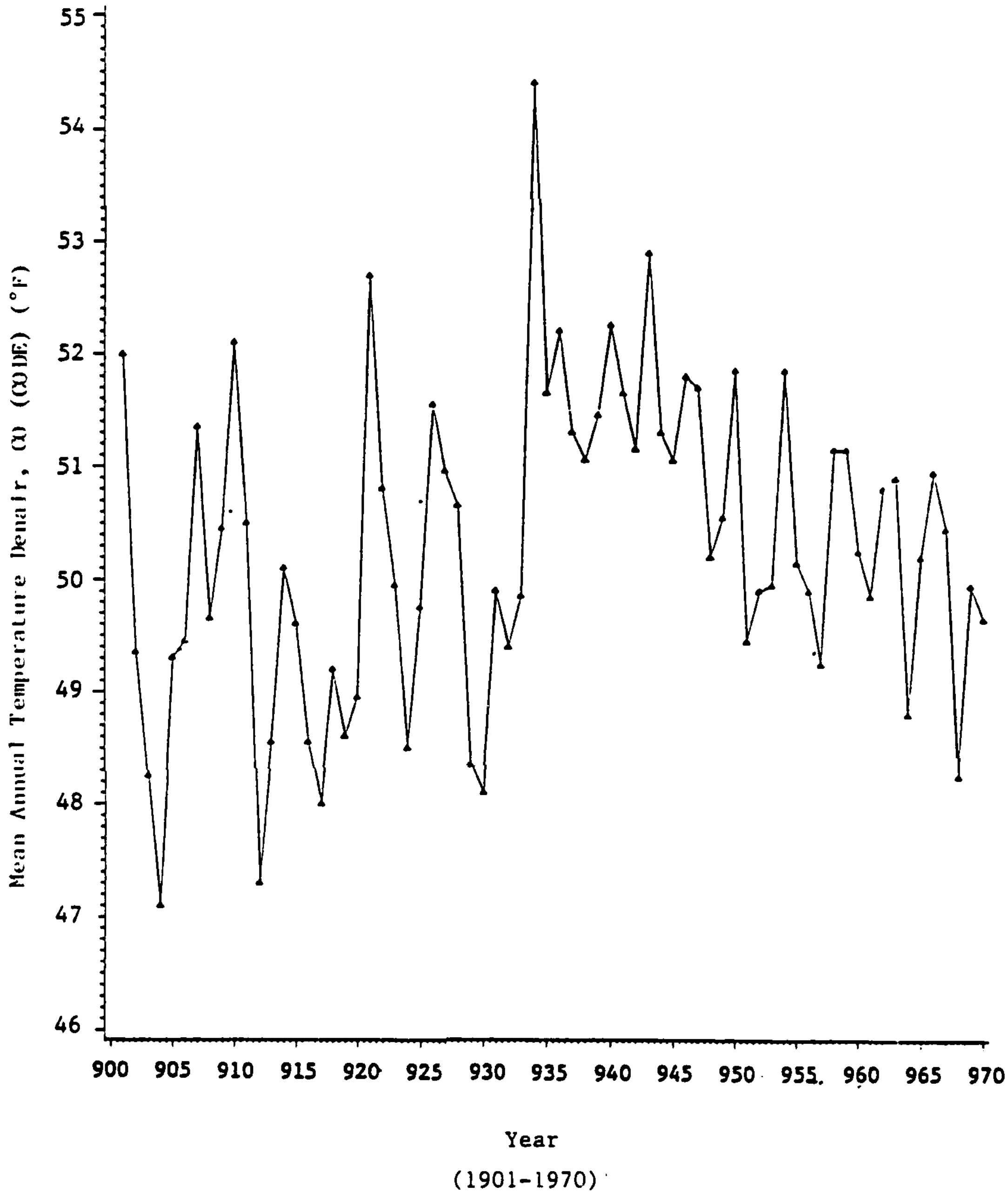


Fig. 14b. Mean annual temperature for CODE 1901-1970.

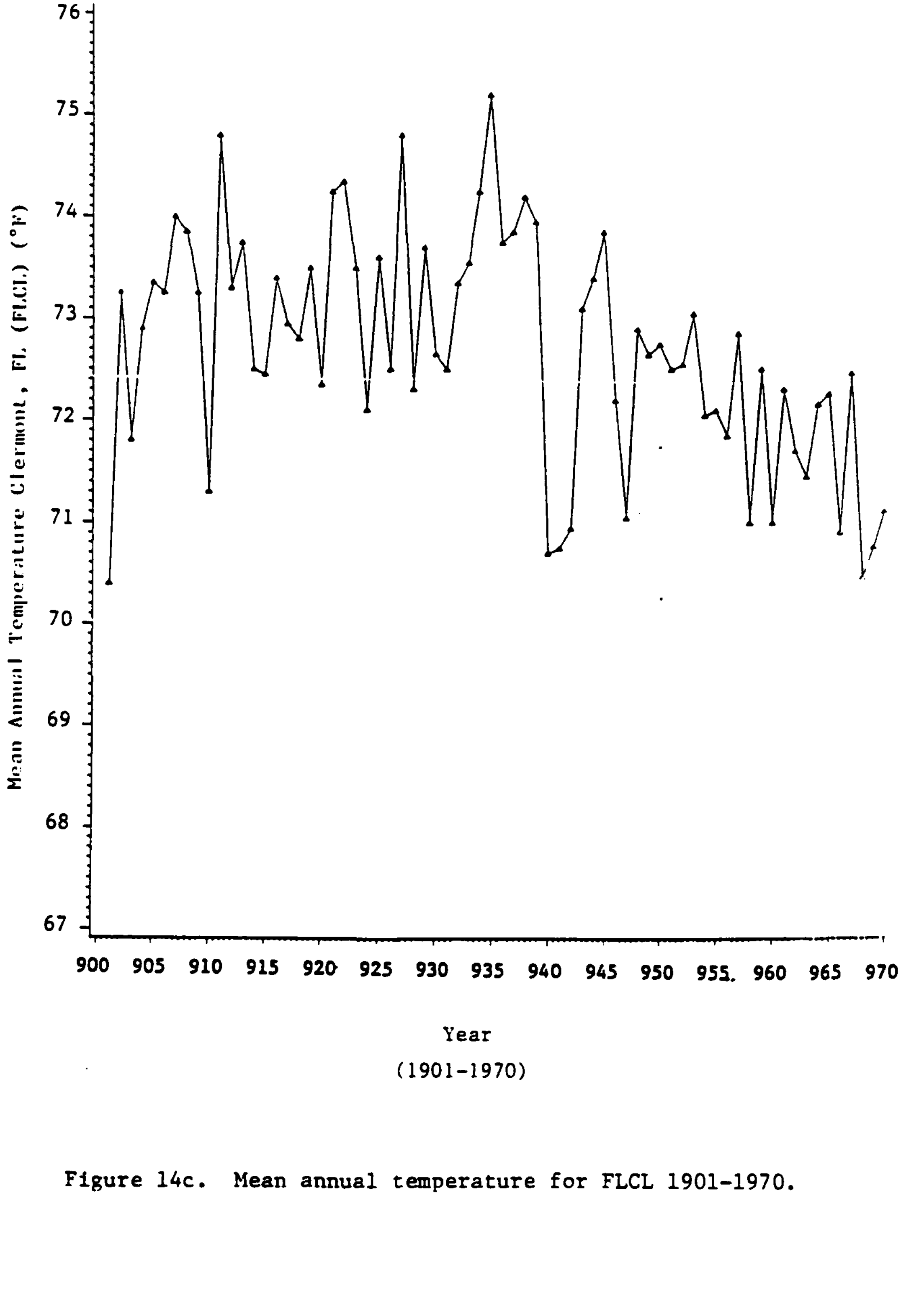


Figure 14c. Mean annual temperature for FLCL 1901-1970.

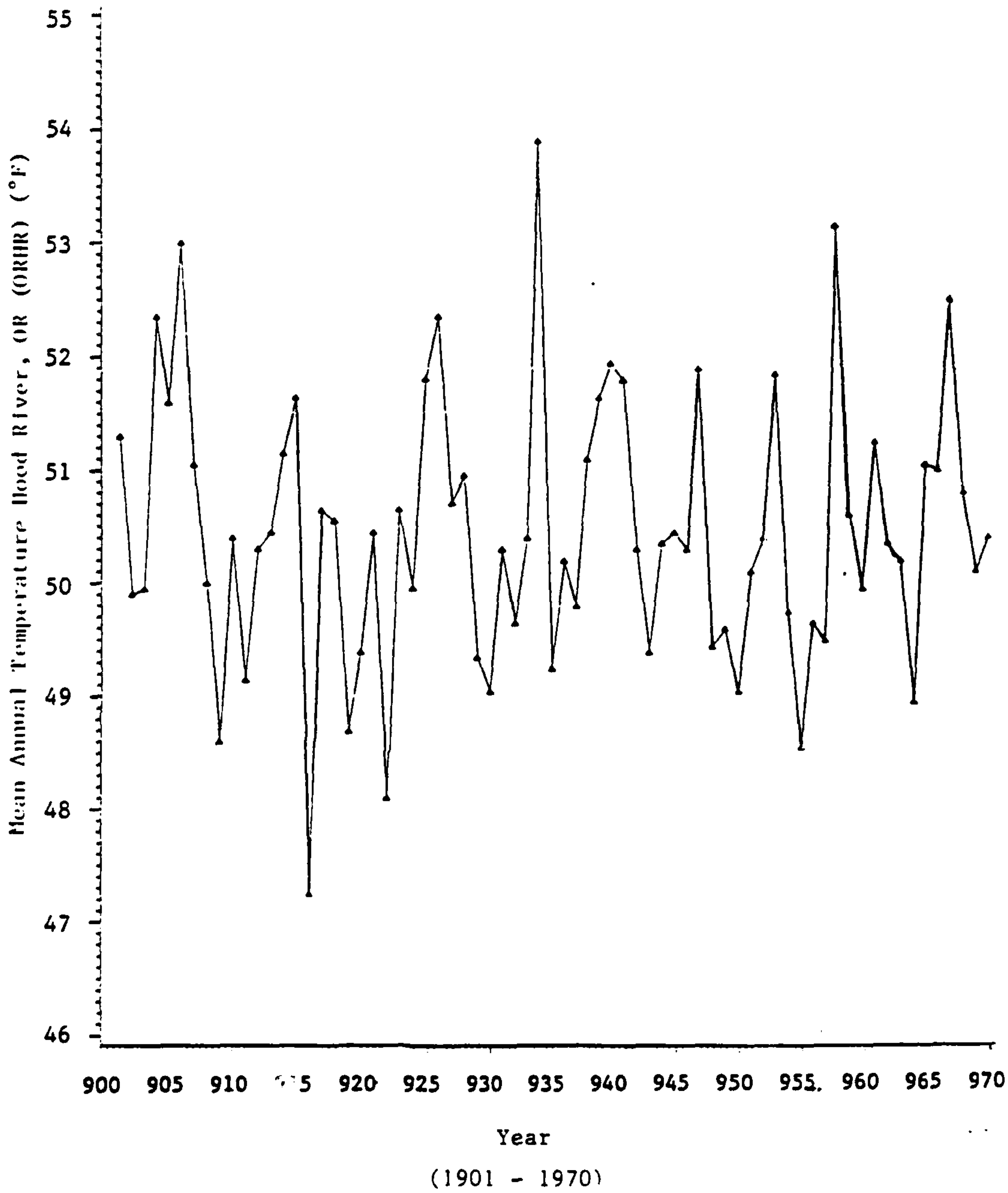
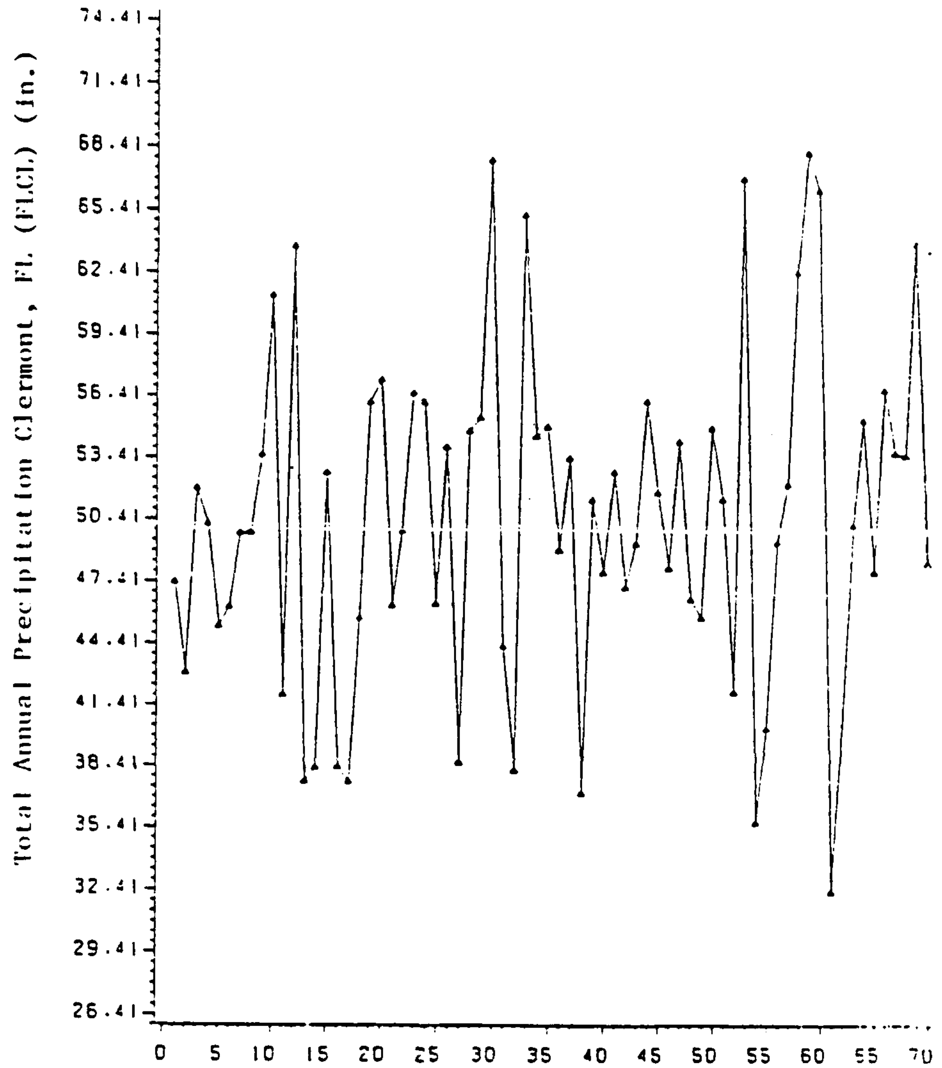


Figure 14d. Mean annual temperature for ORHR 1901-1970.



Year
(1901 - 1970)

Figure 14e. Total annual precipitation FLCL 1901-1970.

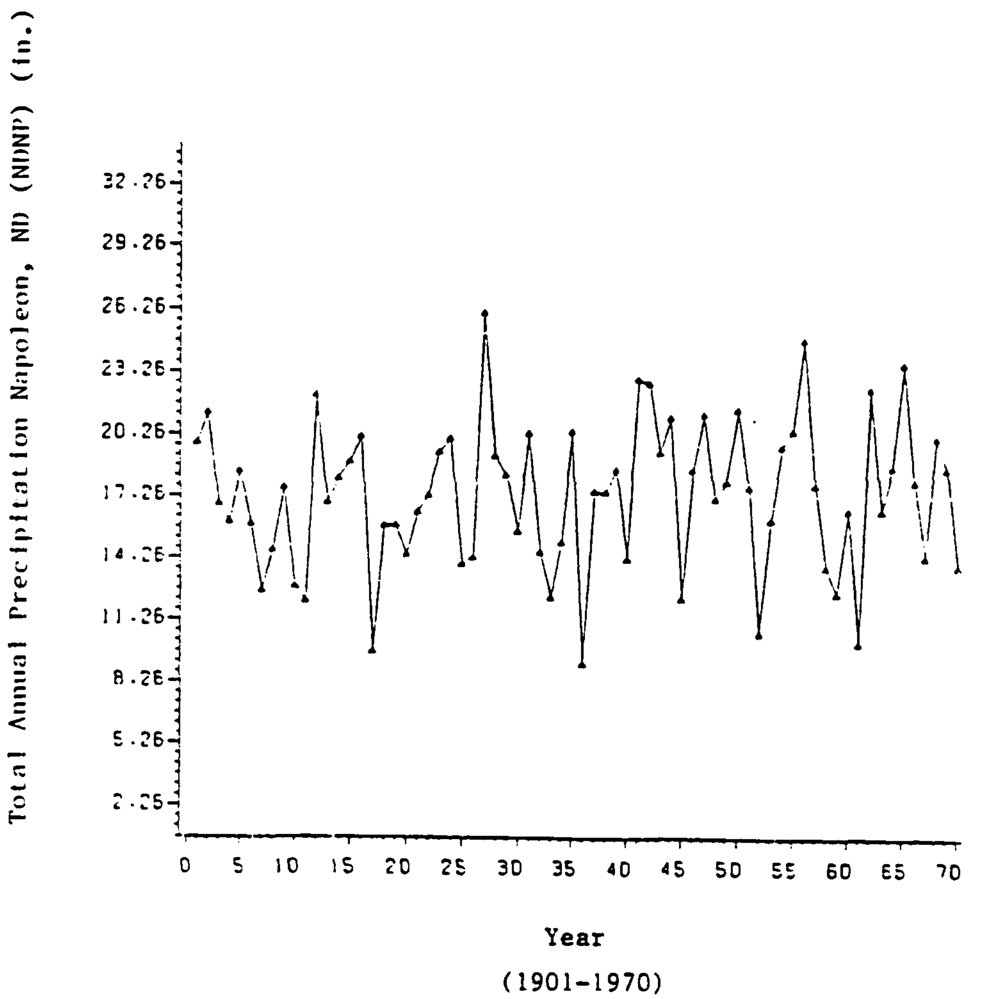
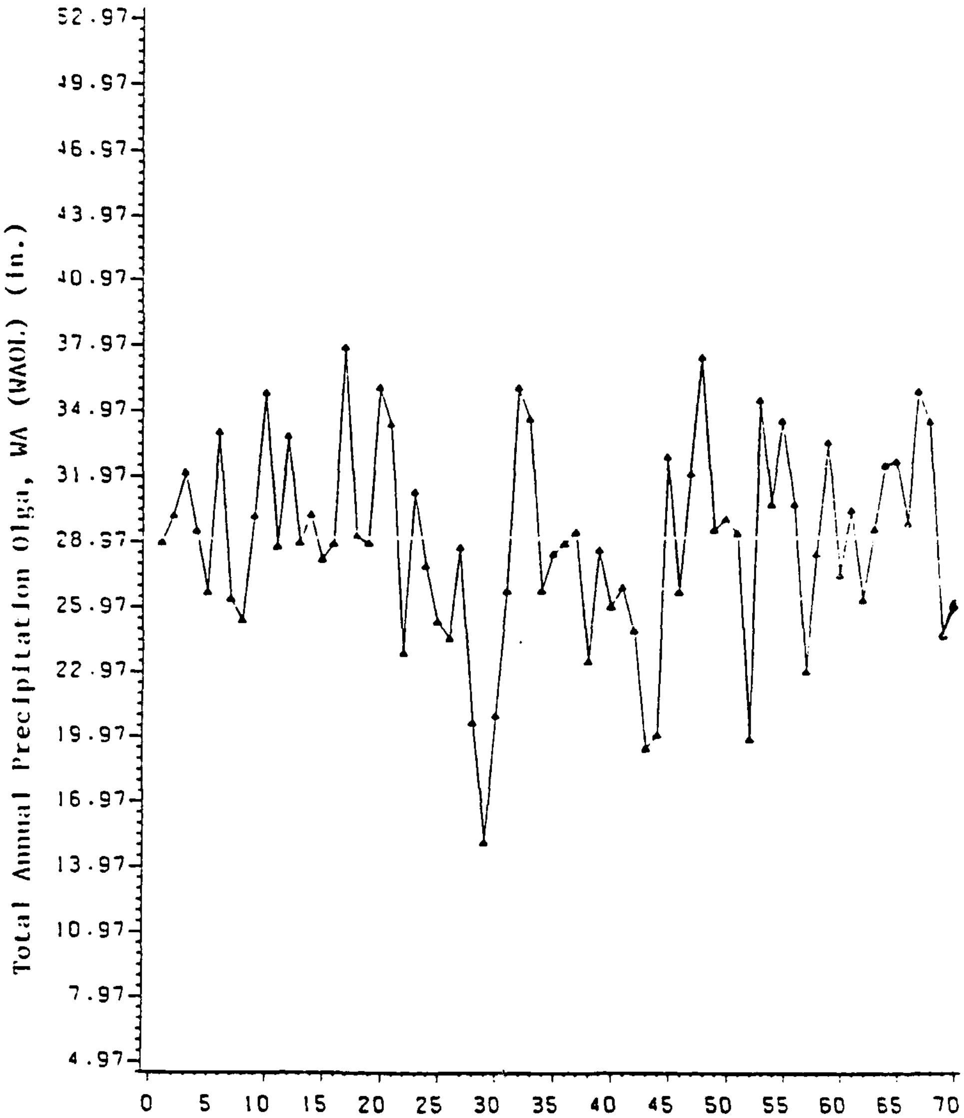


Figure 14f. Total annual precipitation for NDND 1901-1970.



Year

(1901-1970)

Figure 14g. Total annual precipitation for WAOL 1901-1970.

annual temperature using regional means (1893-1977). The graph of the series of mean annual temperature produced by Diaz and Quayle is given in Figure 15 and compares quite well with the one produced in this study (Figure 12b). For example, the same extremes apparently exist in both series: 1912, 1917, 1921, 1930, 1931, and 1934; however, since the data points in Diaz and Quayle's graph are not plotted individually, it is not possible to determine with great accuracy how well the graphs in Figures 12b and 15 compare. Thus, it is reasonable to assume that Diaz and Quayle's use of regional means produces results comparable to those found in this study.

d. Trends in Regional and Overall Annual Data

Figures 16a and b show the series of differences from the mean for mean annual maximum and minimum temperature, respectively, for the group of 144 U.S. stations. A cursory inspection of both graphs reveals their striking similarity. The first 15 to 20 years show variations around an approximate mean of 1°F below Average, where 'Average' is defined to represent the 70-year mean for an element. For the next few decades the temperatures increase, with the rate of increase in minimum temperatures more pronounced than that of maximum temperature. From about 1943 to 1953 the temperatures fluctuate widely around a mean of approximately 0.5°F above Average, after which the mean temperature decreases at a rate similar to its earlier increase in the 1920's and 30's. The extreme years of 1917, 1921, and 1931 are reflected in both series; however, 1912, 1934, and 1939 were relatively extreme years for mean maximum temperature, but not for

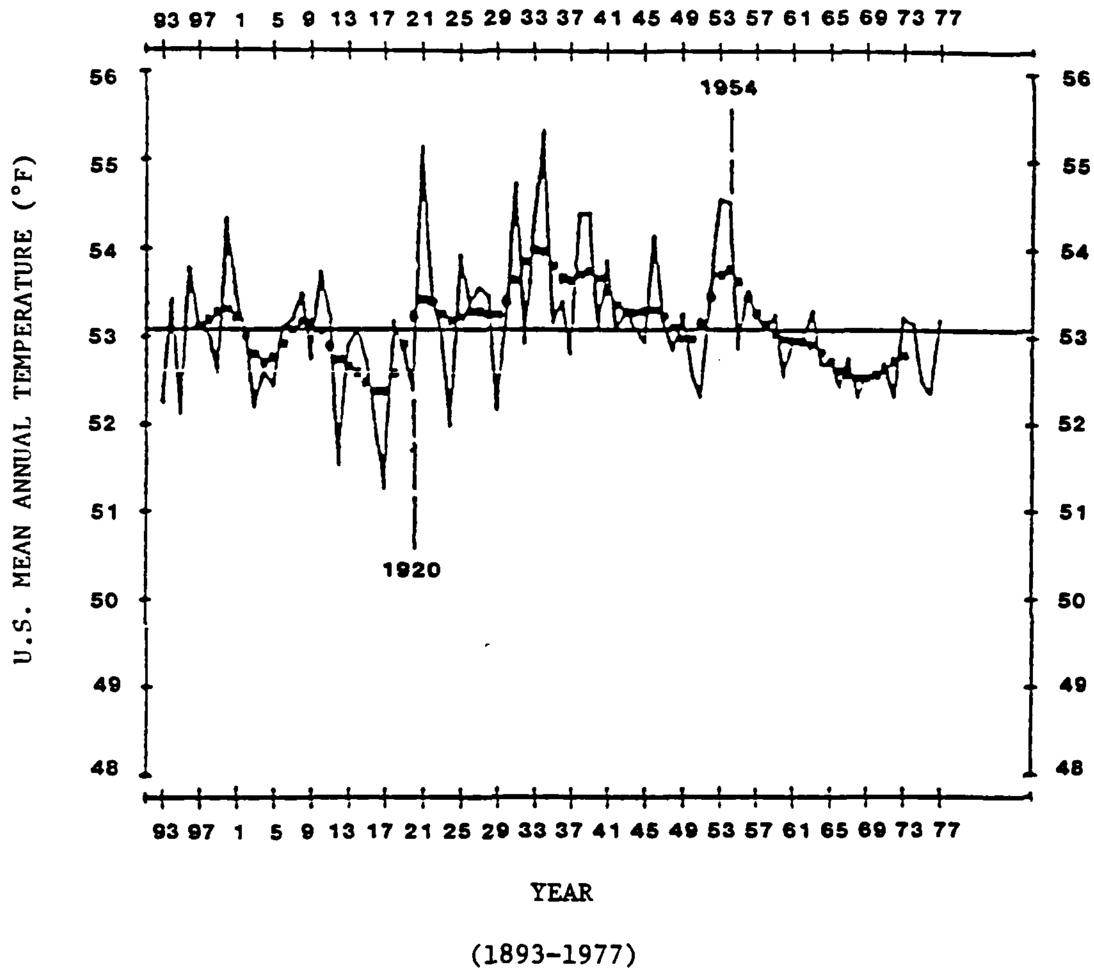


Figure 15. Areally-weighted mean annual temperature for the U.S. (From Diaz and Quayle, 1980).

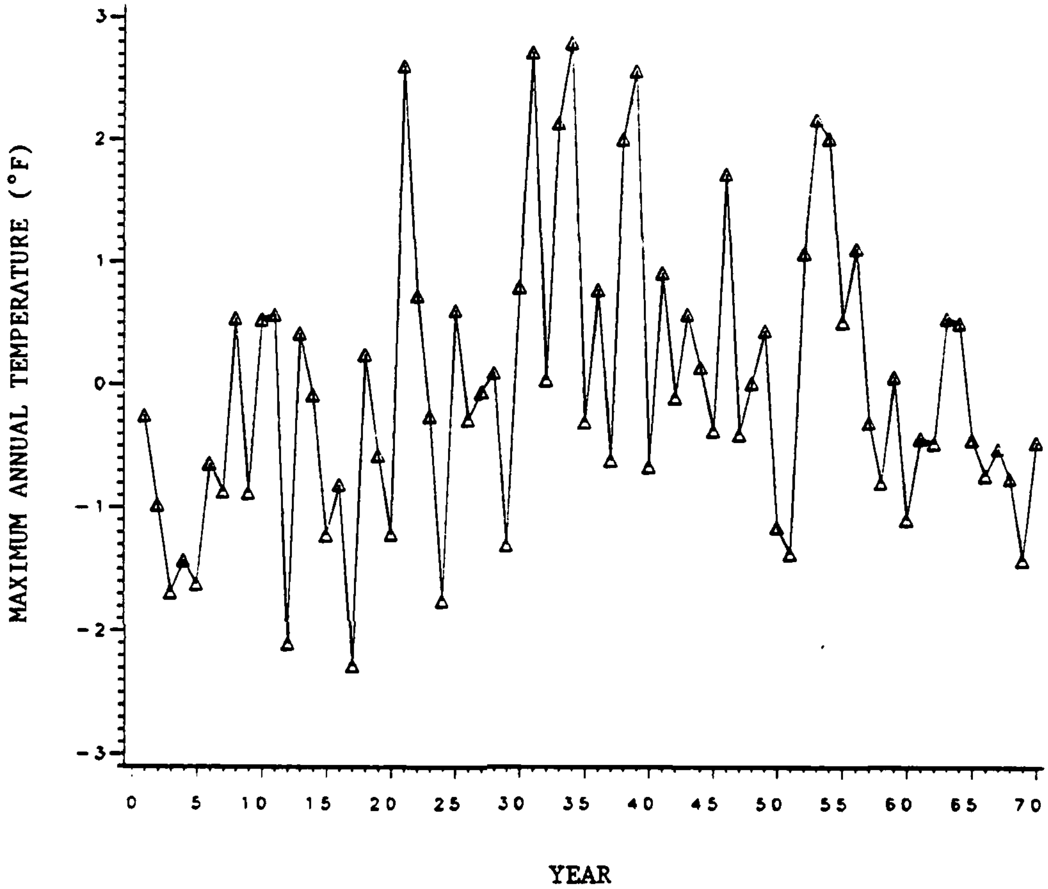


Figure 16a. Yearly pattern of differences from the 70-year mean annual maximum temperature for the 144 U.S. stations, 1901-1970.

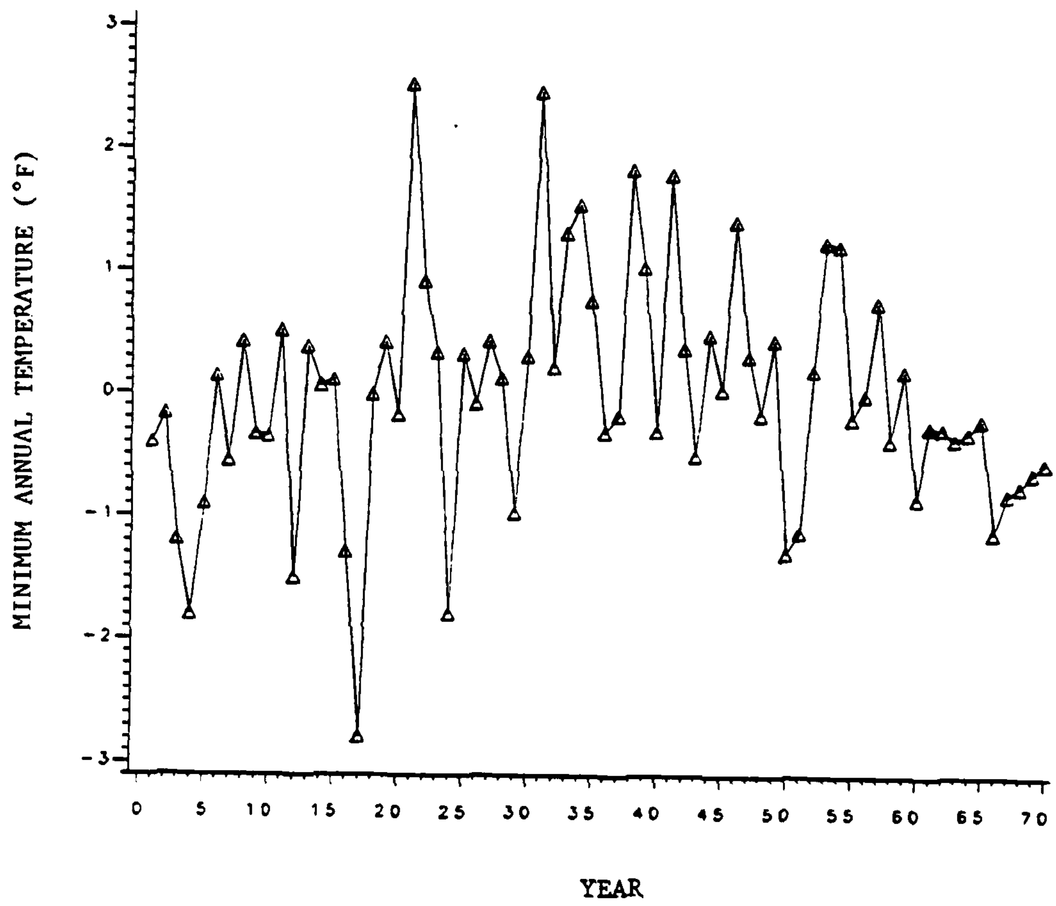


Figure 16b. Yearly pattern of differences from the 70-year mean annual minimum temperature for the 144 U.S. stations, 1901-1970.

mean minimum temperature.

The standard errors of the overall mean maximum and minimum temperatures are shown in Figures 17a and b; the mean standard errors and lines of 2σ departure from the mean are given in the figures as an indication of significance of departures from the mean. The mean standard errors of 0.65 and 0.66 for mean maximum and mean minimum temperatures, respectively, are almost identical, as are the mean standard errors for the differenced data (0.12, maximum and 0.11, minimum). Inspection of Figure 17a reveals that mean maximum temperature was more variable between 1901 and 1917 and less variable between 1957 and 1970 than it was in the intervening period from 1918 to 1956. The graph of standard errors of mean minimum temperatures (Figure 17b) suggests that the minimum temperature series has a pattern of variability similar to that of the maximum temperature series; the first 29 years of the minimum temperature series were more variable and the last 13 years were less variable than the period from 1930 to 1957. The relatively great spatial variability existing in the early part of the maximum temperature series was accompanied by a large temporal variability; for example, the mean of the absolute value of the successive difference of standard errors for the years 1903 through 1912 was 0.063 compared with an average absolute successive difference of 0.026 between 1913 and 1925. It is notable that the graphs in Figures 17a and 17b contain several different periods of greater than average temporal variability, where 'average temporal variability' is defined as the overall mean of the absolute differences of standard errors for successive years for the period

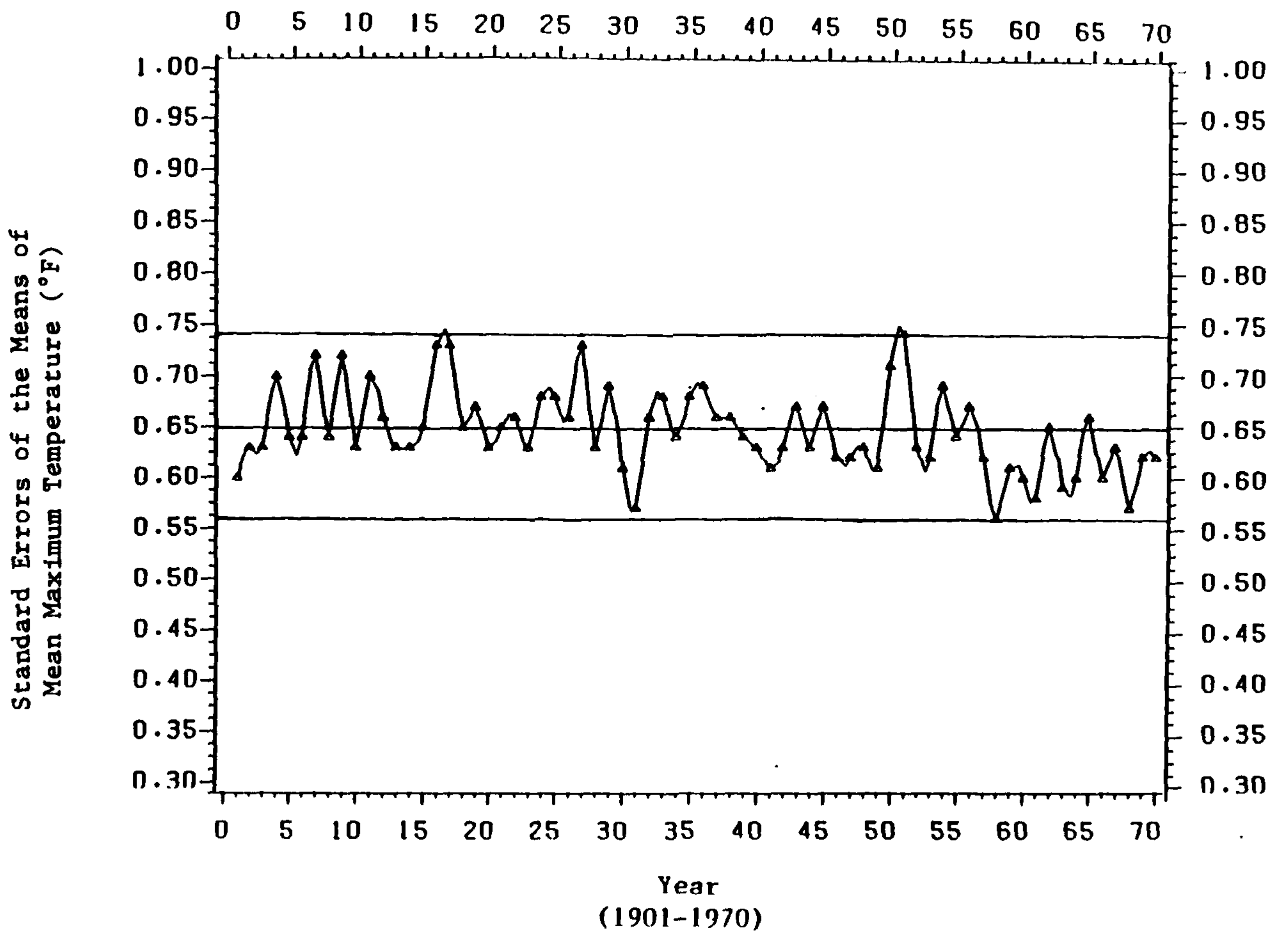


Figure 17a. Standard errors of the means of mean maximum temperature, 1901-1970.

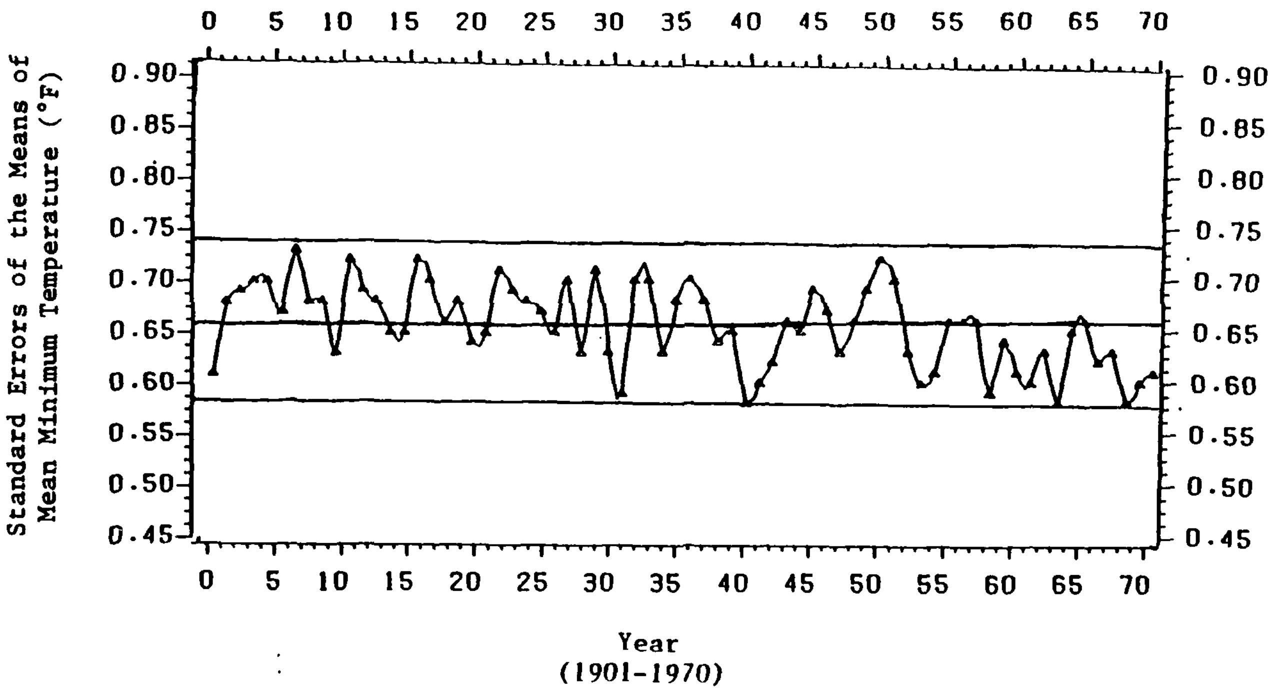


Figure 17b. Standard errors of the means of mean minimum temperature, 1901-1970.

1901-1970. No extraordinary features can be seen in the graph of the standard errors of the differenced data, shown as Figures 18a and b, but it is necessary to note the large difference between these standard errors and those of the raw data. Previous researchers have generally used raw data in their climatic trend analysis; it is clear that an analysis of the differenced data introduces less error than does the traditional approach.

It was previously noted that mean maximum and mean minimum temperatures sometimes exhibit different temporal patterns; however, the pattern of overall mean annual temperature is in general agreement with both series. The weighted mean annual temperature series, Figure 19, exhibits three definite patterns in the period 1901-1970. The first 29 years were relatively cool with an average 0.31°F below the 70-year Average. The drought years of the 1930's and part of the following decade were warmer than average with a mean 0.69°F above Average. 1947-1970 were years of near Average temperature; the mean for this period was only 0.11°F below Average.

Figure 20 gives the graph of weighted total annual precipitation for 1901-1970. The series shows five distinctive periods of similar precipitation. Prior to 1930 the precipitation was near Average. 1930 to 1939 were drought years with Average precipitation only 93% of Average. A t-test of the means for the periods 1901-1929 and 1930-1939 revealed a t-ratio of 2.702 which is significant at the 0.05 level; a t-ratio of approximately 2.720 gives significance at the 0.01 level. The drought years were followed by a period of greater than Average precipitation (105% of Average). Dry weather once again

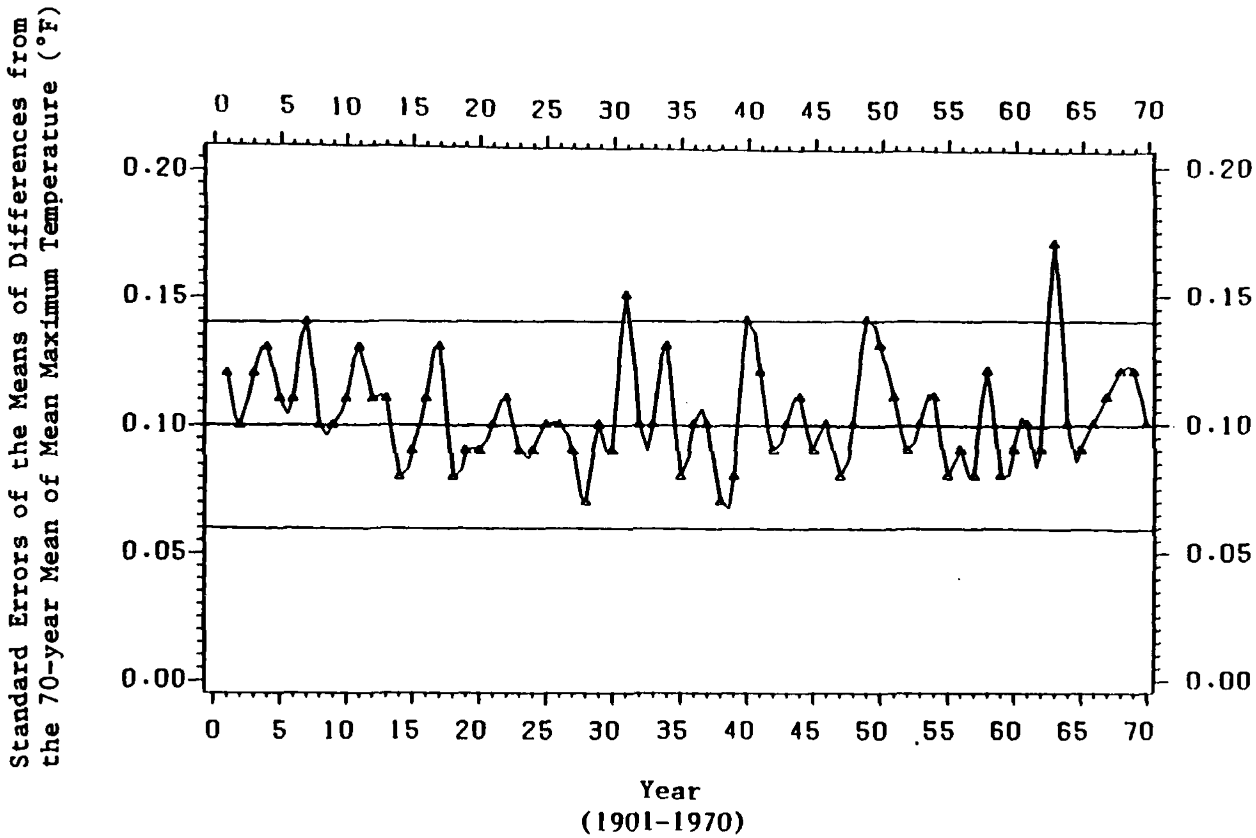


Figure 18a. Standard errors of the means for mean maximum temperature expressed as a difference of the 70-year mean.

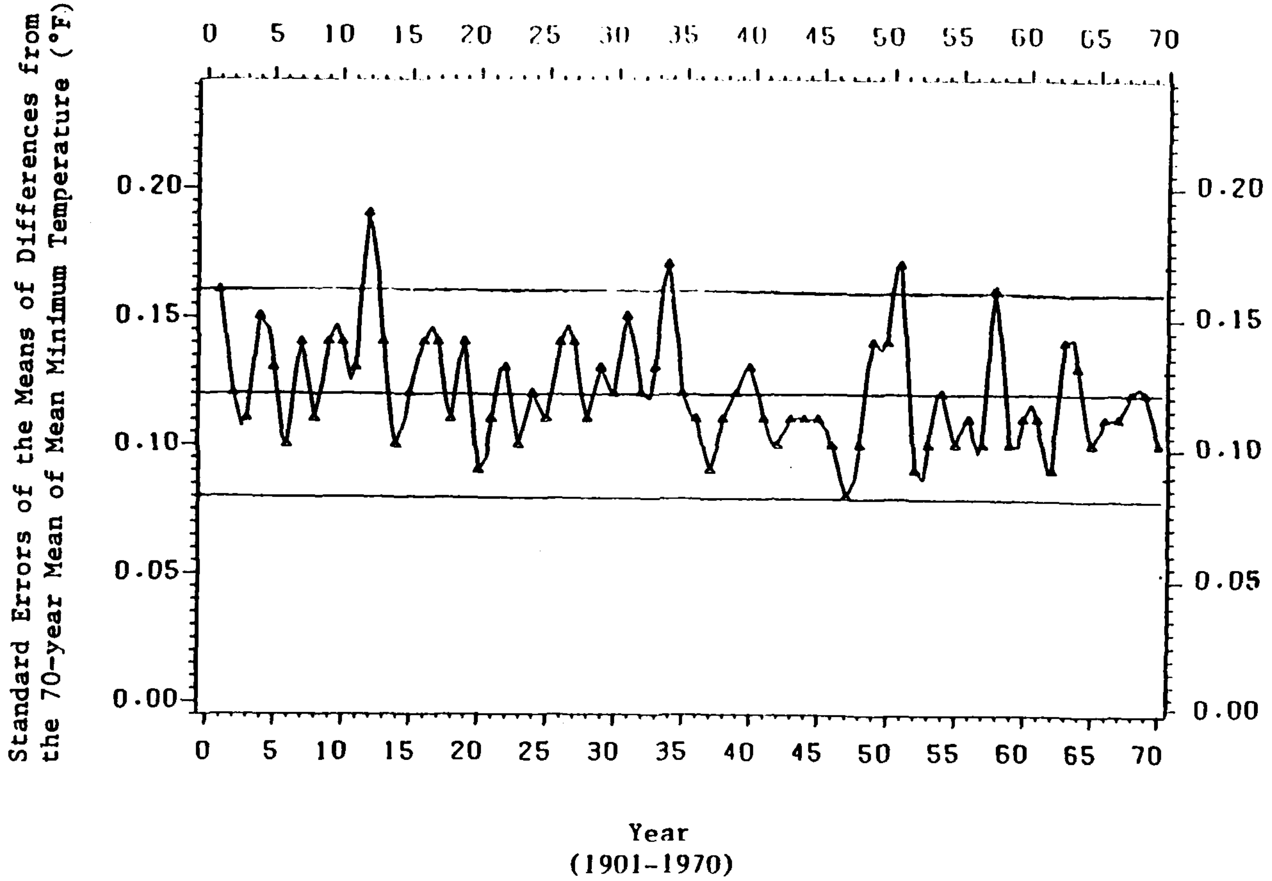


Figure 18b. Standard errors of the means for mean minimum temperature expressed as a difference of the 70-year mean.

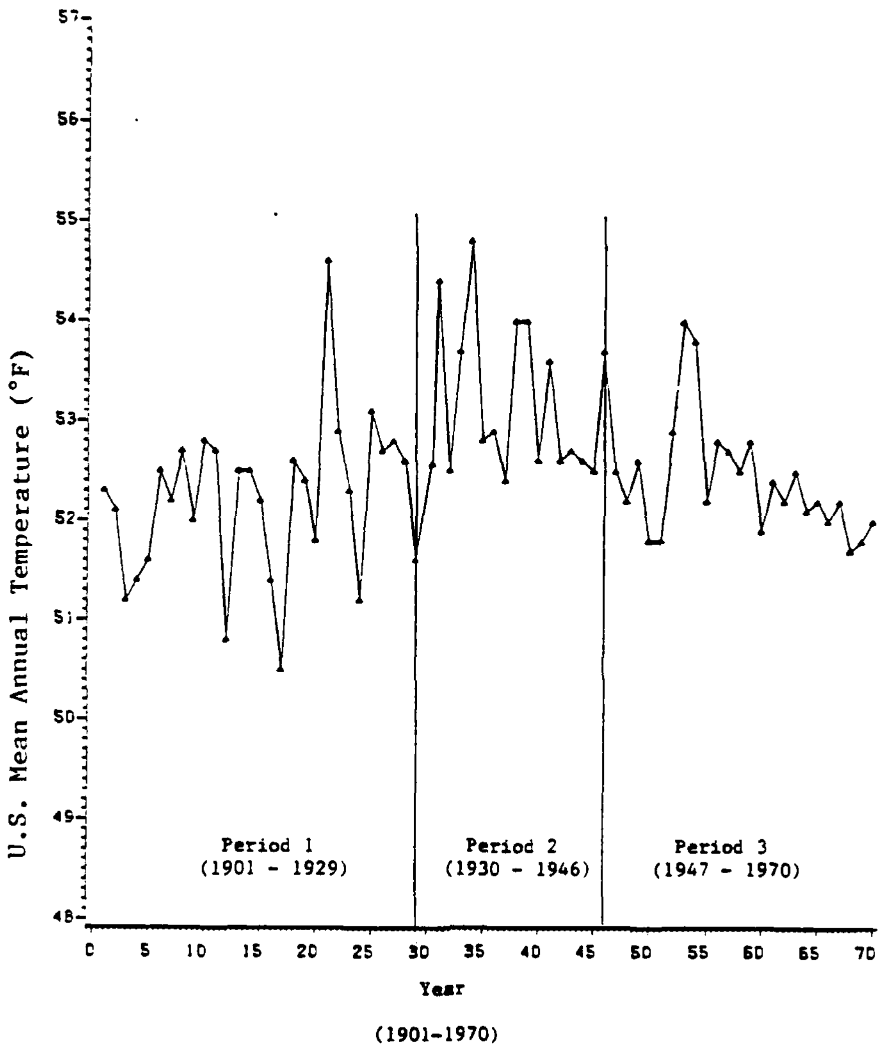


Figure 19. Periods of similar temperature for the U.S. 1901-1970.

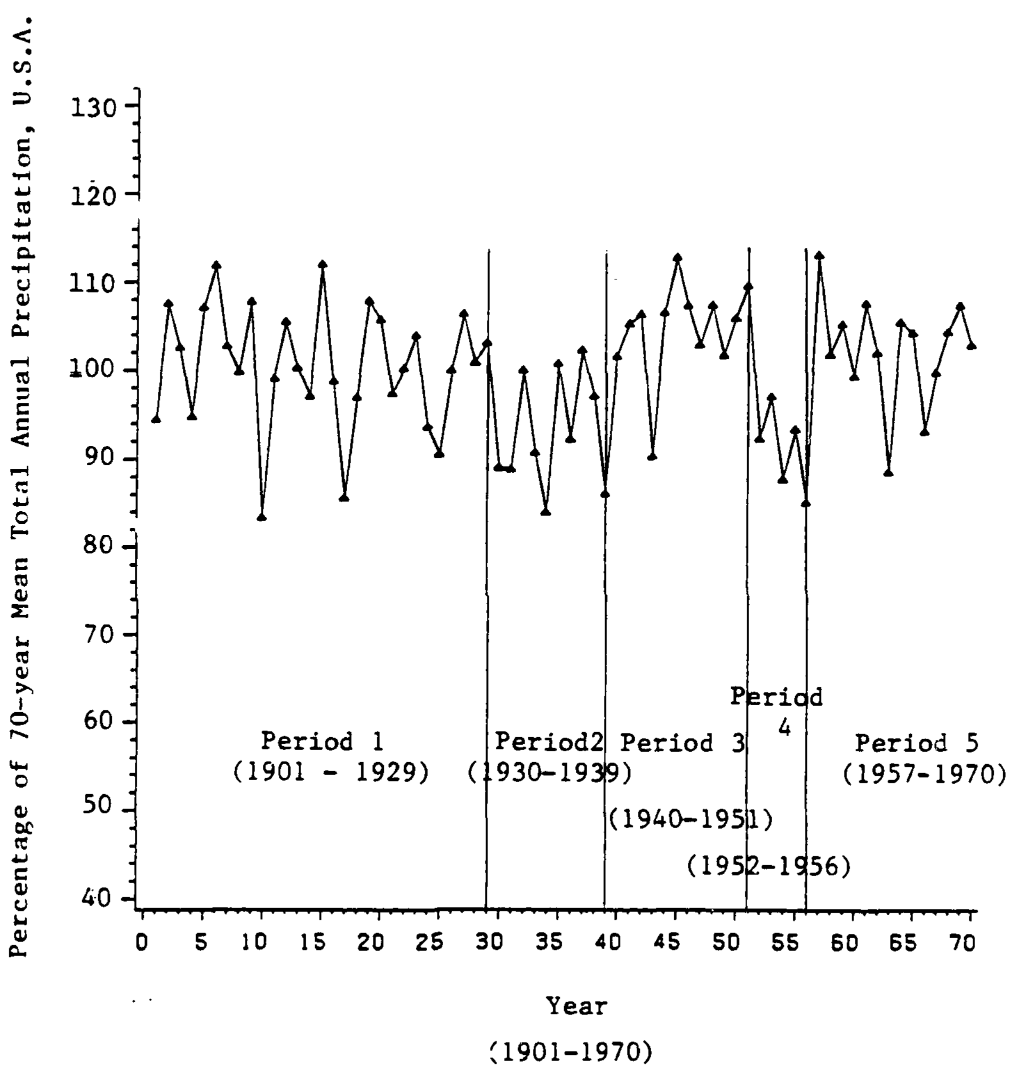
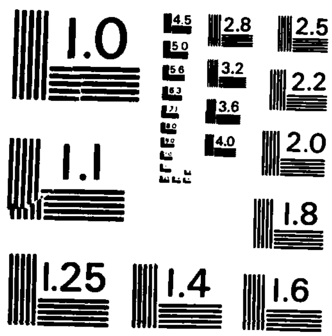


Figure 20. Periods of similar precipitation for the U.S. 1901-1970, using the differences from the 70-year area-weighted mean.

AD-A166 743 SECULAR CLIMATIC PATTERNS OF THE NORTH CENTRAL GREAT PLAINS AND THE CONTINENTAL US(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH K J PRANER 1985 2/2

UNCLASSIFIED AFIT/CI/NR-86-51T F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

predominated between 1952 and 1956 and was followed by 14 years of near Average precipitation. The comparison of various regional means to the overall mean and comparison between regions can be readily determined from Table 11 which summarizes the above discussion of precipitation and temperature patterns.

Previous researchers have suggested that there was a trend of increasing temperature until approximately 1940. The above discussion of definite periods of similar temperature patterns indicates that there is another way to express the manner in which temperature changed during that time: there were two definite periods with significantly different means. A linear regression was performed on the mean annual temperature data for the period 1901-1946 and separately on the sub-periods 1901-1929 and 1930-1946. Coefficients of determination (r^2) near zero for both sub-periods (0.06 and 0.08, respectively), indicated no significant trend within those periods; the F-ratios of 2.81 and 3.83, respectively, are not significant at the 0.05 level. The r^2 of 0.22 for 1901-1946 taken as one period is much more indicative of a significant trend toward higher temperatures; after the Z transformation was applied, the F-ratio of 15.46 exceeds the limit required for significance at the 0.01 level (7.24).

Precipitation series reflected some definite patterns such as have been shown for temperature. McGuirk (1982) advanced the theory that there have been changes in precipitation regimes along the west coast of the U.S. and Canada. He asserts that there is the possibility of multiple steady states of climate. The results of this

Table 11. Means of previously determined periods of similar temperature and precipitation for overall mean (weighted) series and for regions. (Temperatures are in °F. Precipitation is in in..)

Temperature

		Region						
Period	Mean	1	2	3	4	5	6	7
1901-1929	52.2	52.3	44.1	49.1	42.3	64.0	49.4	50.7
1930-1946	53.2	52.8	47.4	52.5	43.6	64.7	50.5	52.2
1947-1970	52.4	52.0	43.0	47.6	43.3	63.6	49.7	51.1
1900-1970	52.5	52.3	44.5	49.4	43.0	64.0	49.8	51.2

Precipitation

		Region					
Period	Mean	1	2	3	4	5	6
1901-1929	29.55	21.03	17.87	47.30	40.66	35.63	32.98
1030-1939	27.37	19.60	16.33	40.25	39.34	32.74	29.32
1940-1951	30.82	22.87	18.62	50.88	41.63	36.03	34.32
1952-1956	26.80	22.01	15.37	43.24	41.70	32.96	26.29
1957-1970	30.14	23.07	18.56	51.10	38.28	34.90	32.84
1901-1970	29.38	21.62	17.74	47.38	40.24	34.95	32.18

study tend to substantiate McGuirk's theory of multiple steady states. In this present study it was possible to interpret different periods of mean annual temperature and precipitation: for example, it is possible that a different temperature regime existed between 1901 and 1929 than the one which prevailed after that time to 1946. The means of the two sub-periods, 1901-1929 and 1930-1946, were tested using the t-test and were found to be significantly different at the 0.001 level. It is important to identify trends of means of climatic elements, but it is equally important to recognize definite changes in patterns of variances of those elements. Long-term changes such as an increase in the concentration of CO_2 can cause temperatures to increase steadily over a long period, but a change in the rate of solar insolation could cause a sudden change in temperatures as was found in this study. A change in solar insolation of as little as 0.05% could produce a shift in temperature of 1°F. Thus, the distinction must be made between trend and sudden change in the fluctuation of climatic elements.

Previous researchers have used a variety of techniques to arrive at the conclusion that there was a trend of increasing temperature from the beginning of the century to 1940 followed by a trend of decreasing temperature. Some researchers have used smoothing techniques which may seriously distort climatic series. Willett (1950) and Mitchell (1963) used differences of non-overlapping pentades to arrive at the conclusion that trends of increasing and decreasing temperature existed. Figure 21 represents application of Mitchell's and Willett's method to the data used in this study. No

trend is evident using their method with the data of this study. This is a strong indication that the stations Willett and Mitchell used were affected by urbanization or other factors which contaminated their data.

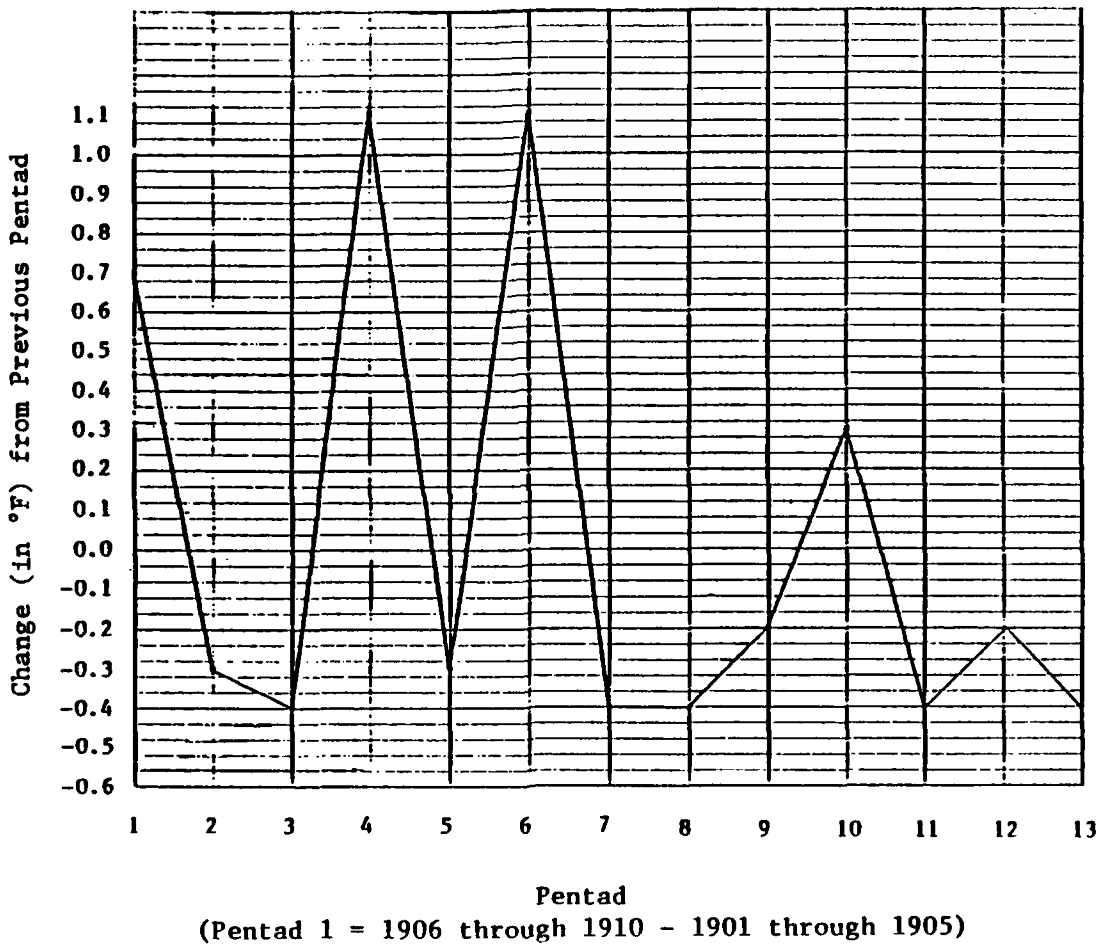


Figure 21. Willett and Mitchell's differencing of non-overlapping pentads applied to the mean annual temperature series of this study.

6. CONCLUSIONS AND RECOMMENDATIONS

a. Conclusions

A substantial data base was compiled under the auspices of this study. The data cover the period 1900-1970 and are comprised of observations from 144 U.S. stations with superior records based on lack of missing data, excellent observing standards, minimal station relocations and negligible effects of urbanization. Monthly mean maximum and mean minimum temperature as well as monthly total precipitation are included in the data base.

Series of annual, winter, and summer means were determined for mean, maximum, and minimum temperatures and for total precipitation. Different representations of the data used included raw data, deviations from the 70-year mean (temperature), and percentages of the 70-year mean (precipitation). The use of deviation from the 70-year mean and percentage of the 70-year mean provided a basis of comparison between stations and regions; there was an immediate indication of how far above or below 'average' a station's or region's mean annual temperature or precipitation was for any particular year.

Various grouping techniques were applied to 39 stations in the north central great plains (NCGP) to find an appropriate method of dividing an area into regions of similar climatic pattern. The method of correlating means of individual stations to the overall area mean was then applied to the 144 U.S. stations of this study. Patterns of mean annual temperature and total annual precipitation were determined for the U.S. as one entity and by region. The U.S. was divided into seven groups of similar mean annual temperature and six groups of

total annual precipitation; groupings were determined by correlating values of temperature and precipitation for individual stations to the overall mean values for their respective elements. The mean annual temperature and total annual precipitation series of the regions were weighted by the size of their regions to produce an area-weighted average mean annual temperature and total annual precipitation series for the U.S. The temperature series for the U.S. as previously determined was an average of only 0.1°F higher than the area weighted series for each year. However, the area weighted precipitation series revealed amounts of precipitation approximately 1.00 in/year less than the original series for total annual precipitation. This large discrepancy in the area weighted and original total annual precipitation series is due to the fact that the relatively dry western U.S. spans approximately 40% of the U.S., but is represented by less than 20% of the stations in the 144 station sample of this study.

Diaz and Quayle's (1980) areally weighted mean temperature series based on regional climatic data is similar to the one produced in this study; this is an indication that means of climatic divisions can provide a reliable set of climate information if the divisions are adequately represented.

It was noted that variability of all temperature series was nationally lower in the seventh decade (1961-1970) than it was during other decades. Time series analysis of a representative 70-year series of temperature for a station indicated the data were stochastic.

The pattern of temperature in the overall U.S. mean annual temperature series apparently consists of three distinctive periods. The drought years of the 1930's and subsequent interval of time through 1946 were times of significantly higher temperature than the period before or after it. Thus, it is misleading to state that there was an upward and downward trend during the period, where "trend" is as defined by Landsberg (1975); however, this is what was stated in early research of climatic trends. The method of analysis, particularly the use of smoothing techniques, can distort the data to such an extent that important information is lost.

Precipitation across the U.S. during the period 1901-1970 showed five patterns: 1901-1929 were years of average precipitation. 1930 to 1939 were dry years. Greater than average precipitation prevailed from 1940 to 1951 followed by five dry years. 1957 to 1970 were years of near average precipitation.

The periods of similar temperature and precipitation put forth in this study are subjectively determined; others could choose periods which vary by several years, however, it is submitted that the period from approximately 1930 to 1946 was a time of anomalously high temperature; previously established trends of temperature cannot be supported when the data of superior stations are analyzed.

Regional patterns of temperature and precipitation show similarities to their respective overall mean series, but there are distinct differences. Any climatic study which combines data for one area as large as the continental U.S. is neglecting important information. In this study, the central U.S. was well represented by

the overall U.S. series, but the far eastern and western U.S. had different patterns which were not represented in the mean series.

Several investigators have based their studies on regional data, yet others continue to make wide-sweeping conclusions based on analysis of large areas. This study is similar in concept to previous investigations by Lawson et al. (1981), Diaz and Quayle (1980), and Walsh et al. (1982), among others. Regions determined by Lawson and Walsh are similiar to those determined in this study. The periods of distinct temperature and precipitation found by Diaz and Quayle are not the same ones found in this study, however the concept is the same. It is necessary to inspect actual climatological series to find periods which warrant further study before applying various smoothing techniques to the data. Generally, the smaller the region analyzed, the more reliable will be patterns that emerge from the analysis. One major exception to the previous statement deals with regions with obvious topographical inconsistencies such as mountainous regions. In general, the more geographically similar a region is, the more reliable will be the patterns which emerge from analysis of the region.

b. Recommendations

(1) A study should be conducted to determine if the patterns of temperature and precipitation found in this study are compatible with state and regional means based on areally weighted climatic divisions.

(2) A concerted effort should be made to preserve the high quality stations with long-standing records which have been identified in this study.

(3) Determination of the role of changing temporal variability in climate change should be studied.

(4) A continuation of this study to include data through 1985 should be accomplished to determine if any change in patterns exist based on the inclusion of more recent data. The continued study should also determine if the reduced variability of the 1960's has persisted.

Important insights into establishment of synoptic patterns could result from a study of regional patterns of temperature and precipitation. Monthly or seasonal patterns correlated with various synoptic conditions may result in a better understanding of how synoptic patterns develop and change.

REFERENCES

Angell, J. K. and J. Korshover, 1975: Estimate of the global change in tropospheric temperature between 1958 and 1973. Mon. Wea. Rev., 103, 1007-1012.

__________, 1978: Global temperature variation, surface-100mb: an update into 1977. Mon. Wea. Rev., 106, 755-770.

Brooks, C. E. P. and N. Carruthers, 1953: Handbook of statistical methods in meteorology. Her Majesty's Stationary Office, London. 412pp.

Budyko, M. I., 1982: The earth's climate: past and future, Academic Press, New York, NY. 307pp.

Callendar, G. S., 1961: Temperature fluctuations and trends over the earth. Quart. J. Roy. Meteor. Soc., 87, 1-12.

Conrad, V. and L. W. Pollak, 1962: Methods in climatology. Harvard University Press, Cambridge, MA. 459pp.

Diaz, H. F. and R. G. Quayle, 1980: The climate of the United States since 1895: Spatial and temporal changes. Mon. Wea. Rev., 108, 249-266.

Dronia, H., 1974: Uber temperaturanderunden der freien atmosphare auf der Nordhalbkugel in den letzen 25 jahren. Meteor. Rundsch. 27, 166-174.

Geary, R. C., 1935: The ratio of the mean deviation to the standard deviation as a test of normality. Biometrica, 27, 310.

Hart, B. I., 1942: Significance levels for the ratio of the mean square successive difference to the variance. Ann. Math. Stat., 13, 445-447.

Kellogg, W. W., 1977: Effects of human activities on global climate. Tech. Note No. 156. World Meteorological Office No. 486. Geneva, Switzerland. 47pp.

Kraus, E. B., 1954: Secular changes in the rainfall regime of S. E. Australia. Quart. J. Roy. Meteor. Soc., 80, 591-601.

__________, 1955a: Secular changes of tropical rainfall regimes. Quart. J. Roy. Meteor. Soc., 81, 198-210.

__________, 1955b: Secular variations of East-coast rainfall regimes. Quart. J. Roy. Meteor. Soc., 81, 430-439.

Landsberg, H. E., 1975: The definition and determination of climatic changes, fluctuations and outlooks. University of Maryland, Publ. No. 117, Graduate Program in Meteorology, MD. 19pp.

Landsberg, H. E. and J. M. Mitchell, Jr., 1961: Temperature fluctuations and trends over the Earth. Quart. J. Roy. Meteor. Soc., 87, 435.

Lawson, M. P., R. C. Bailing, Jr., A. J. Peters and D. C. Rundquist, 1981: Spatial analysis of secular temperature fluctuations. J. Clim., 6, 325-332.

Love, J. H., Jr., 1985: The selection of climatic-variation reference stations in the continental U.S. using historical information and statistical methods. M.S. Thesis, Department of Meteorology, Texas A&M University. 67pp.

Mc Guirk, J. P., 1982: A century of precipitation variability along the Pacific coast of North America and its impact. Clim. Change, 4, 41-56.

Mitchell, J.M., Jr., 1953: On the causes of instrumentally observed secular temperature trends, J. Meteor., 10, 244-261.

__________, J.M., 1961: Recent secular changes of global temperature. Ann. New York Academy Sci., 95, 235-250.

__________, 1963: On the world-wide pattern of secular temperature change. Changes of Climate, U.N.E.S.C.O., Arid Zone Research Series XX, Paris, 161-181.

__________, 1966: Climatic change. Tech. Note No. 79. World Meteorological Office No. 195, Geneva, Switzerland. 79pp.

Morgan, W. A., 1960: Determination of the straight line of best fit to observational data of two related variates when both sets of values are subject to error. Quart. J. Roy. Meteor. Soc., 186, 107-113.

Newton, H. J., 1983: An introduction to the methods of time series analysis in the time and frequency domains. Institute of Statistics, Texas A&M University, College Station, TX. 112pp.

Panofsky, H. A., and G. W. Brier, 1968: Some applications of statistics to meteorology. The Pennsylvania State University, State College, PA. 224pp.

SAS Institute Statistical Analysis System 1982: SAS User's Guide: Statistics. SAS Institute, Cary, NC., 584pp.

__________, 1926, 1933: Bulletin W, Washington, D. C.

U.S. Department of Commerce, 1940-1970: Climatological data, Washington, D. C.

__________, 1955: Bulletin W, Washington, D. C.

__________, 1956: Substation history, Washington, D. C.

__________, 1968: Climatic atlas, Washington, D. C.

van Loon, H. and J. Williams, 1978: The association between mean temperature and interannual variability. Mon. Wea. Rev., 106, 1012-1017.

Walsh, J. E., M. B. Richman and D. W. Allen, 1982: Spatial coherence of monthly precipitation in the United States. Mon. Wea. Rev., 110, 272-286.

Willett, H. C., 1950: Temperature trends of the past century. Cent. Proc. Roy. Meteor. Soc., 195-206.

APPENDIX A

Number of months, by decade, for which data were estimated for each variable - mean maximum temperature, mean minimum temperature, and annual total precipitation.

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MAXIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
ALHH	3	0	0	3	5	2	2	0	15
ALCL	7	1	2	0	1	0	0	0	11
ARSU	1	6	1	0	2	0	0	0	10
ARPC	2	0	0	0	0	2	7	0	11
ARPR	0	0	2	0	0	0	0	0	2
CACE	1	4	1	0	0	11	0	0	17
CADE	6	0	1	0	1	0	1	0	9
CANE	2	3	0	0	5	1	0	0	11
CODE	21	0	0	0	0	0	0	0	21
FLCL	0	15	0	0	0	0	0	0	15
GAOU	6	1	0	7	2	9	5	0	30
GAHA	7	5	0	0	2	0	0	0	14
GAMI	13	5	2	1	2	2	5	0	30
IAFA	9	0	1	2	4	0	0	0	16
IACD	0	4	0	1	1	8	0	1	15
IDAS	13	5	0	0	0	0	0	0	18
IDOA	3	0	0	4	5	0	0	0	12
IDPC	24	0	0	0	0	2	0	0	26
INRV	0	4	0	0	0	0	13	0	17
INCC	0	0	0	0	0	0	0	0	0
ILAN	12	4	3	1	0	0	0	0	20
ILGR	0	0	6	0	0	5	2	0	13
ILLH	12	1	1	0	0	0	1	0	15
ILWA	0	1	3	0	0	1	1	0	6
ILMA	12	8	1	0	0	9	0	0	30
ILML	12	2	1	0	1	0	0	0	16
ILPA	2	0	4	1	0	1	0	0	8
ILSP	13	1	0	0	0	0	0	0	14
ILMC	14	3	3	1	0	0	3	0	24
KACS	0	0	0	0	0	0	0	0	0
KYGR	0	2	0	0	4	1	0	0	7
KYIR	0	0	0	3	0	0	0	0	3
KYLF	0	0	1	0	1	0	1	0	3
KYSH	1	1	0	0	0	0	1	0	3
KYWI	4	1	0	12	0	15	0	0	32
LAMV	0	2	2	1	0	2	0	0	7
LAPC	0	1	2	2	3	2	1	0	11
MDWS	8	2	1	0	0	0	0	0	11
MEEP	0	0	0	3	0	0	0	0	3
MEFA	1	1	0	0	5	0	0	1	8
MIAL	0	0	3	0	0	0	11	1	15
MNPI	0	1	0	0	6	1	0	1	9
MNGM	0	0	0	0	0	0	0	0	0
MNPO	0	1	0	1	0	0	0	0	2
MNSL	0	3	0	1	0	0	0	0	4
MNPA	2	1	4	0	1	0	0	0	8
MNLL	2	0	0	0	0	0	0	0	2
MOAC	3	27	0	0	1	0	0	0	31
MOHA	0	1	0	0	0	3	0	0	4
MOLA	0	0	1	0	0	1	0	0	2
MOMH	1	9	8	0	1	0	0	0	19
MOAR	0	5	0	0	0	3	3	0	11
MOBR	0	0	0	0	0	1	0	0	1
MOLS	7	1	3	1	0	1	1	0	14
MOST	0	0	0	0	0	0	0	0	0
MOUN	0	0	0	1	0	0	0	0	1
MSBT	2	0	0	0	1	0	3	0	6
MSPT	0	4	0	1	0	0	0	0	5
MSSC	18	0	2	2	2	0	0	0	24
MTGL	11	7	8	0	2	0	0	0	28
NCSP	5	0	1	0	1	0	3	11	21
NDAM	2	0	0	0	15	0	0	0	17

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MAXIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
NDNP	12	0	0	0	0	2	0	0	14
NHBE	6	4	7	1	0	2	1	0	21
NJBE	3	1	3	2	2	1	0	0	12
NJCB	0	0	0	0	1	0	1	0	2
NJFL	1	0	1	0	0	0	1	0	3
NMFB	0	1	15	0	0	2	3	0	21
NYAN	12	8	0	2	3	0	0	0	25
NYHE	2	5	1	0	0	0	1	0	9
NYLD	3	8	1	0	0	0	1	0	13
NYML	3	0	3	0	1	0	0	0	7
OHPH	1	15	0	0	0	1	0	0	17
OHMP	2	0	0	0	0	0	0	0	2
OKKF	0	0	0	2	0	0	2	0	4
ORHR	4	4	6	1	0	0	0	0	15
SCBV	0	2	9	1	2	2	0	0	16
SCKI	6	3	1	0	0	0	0	0	10
SCSV	0	0	8	0	0	0	0	0	8
SCYE	1	5	0	0	0	0	9	0	15
TNDO	20	8	4	0	0	0	0	0	32
TNRV	0	0	0	1	4	2	1	0	8
TNLB	0	1	1	1	0	0	0	0	3
TXBL	0	0	0	0	0	0	0	0	0
TXLL	15	0	0	0	0	4	0	0	19
TXBA	0	0	0	3	0	0	0	0	3
TXDA	3	0	0	0	0	0	0	0	3
TXHA	0	0	0	0	11	0	0	0	11
UTCD	0	0	0	0	0	0	0	0	0
UTFI	0	0	0	0	0	0	0	0	0
UTMA	22	0	0	0	0	0	0	0	22
UTHE	0	0	0	1	0	3	0	0	4
UTDE	0	2	0	0	1	0	0	0	3
UTLE	0	5	0	0	0	4	0	0	9
VABG	2	0	1	1	0	3	0	0	7
VACD	6	1	3	0	3	0	3	0	16
VAHS	1	6	0	0	0	1	1	0	9
WADA	23	1	0	0	0	0	0	0	24
WAOL	0	1	0	0	0	0	0	0	1
WIME	0	0	0	7	0	1	0	0	8
WIDC	0	2	4	0	8	0	7	0	21
WINE	3	6	0	1	9	2	0	0	21
WVGV	4	0	0	0	4	0	1	0	9
WVWB	1	6	0	0	0	0	0	0	7
WYYP	1	0	0	0	3	1	6	0	11
CDCW	1	0	2	0	0	0	0	0	3
IAHU	0	11	0	0	0	0	0	0	11
IALD	1	0	0	1	0	0	1	0	3
IAMA	0	1	0	0	0	0	19	1	21
IARC	1	2	1	0	0	0	0	0	4
KACD	0	0	0	0	0	0	0	0	0
KAHA	0	0	0	0	0	0	0	0	0
KAHD	0	0	0	0	0	0	0	0	0
KAPH	0	0	0	0	0	0	0	0	0
MNMI	0	4	2	0	0	0	0	0	6
MOCD	0	8	0	1	1	0	0	0	10
MOOR	0	0	4	0	0	0	1	1	6
NEAU	0	0	0	0	19	0	1	0	20
NEBB	19	8	2	0	0	1	2	0	32
NEBC	0	8	3	0	0	0	2	0	13
NEBR	0	4	1	1	0	1	1	0	8
NECR	5	0	1	2	3	0	0	0	11
NEFA	0	0	0	0	2	4	0	1	7
NEGT	3	0	0	0	0	0	0	0	3

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MAXIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
NEGV	1	3	1	0	0	0	0	0	5
NEHA	6	0	0	0	0	0	1	0	7
NEHS	2	1	0	0	0	0	11	0	14
NEIM	0	2	4	1	2	0	0	0	9
NEKI	4	0	6	0	2	4	0	0	16
NELC	4	6	13	0	0	3	1	0	27
NEMA	0	3	9	0	0	1	1	0	14
NEMI	0	2	3	2	0	0	1	0	8
NENL	0	0	0	0	0	0	4	0	4
NESP	0	0	0	0	0	0	0	0	0
NEVA	0	0	0	0	0	0	0	0	0
NEWA	0	10	0	0	3	0	0	0	13
SDAC	0	0	0	0	1	0	6	0	7
SDCL	0	0	0	0	0	0	0	0	0
SDFA	0	0	0	0	0	0	0	0	0
SDFB	0	0	0	0	0	0	1	0	1
SDMB	0	0	0	0	0	5	0	0	5
SDME	0	0	0	0	0	0	0	0	0
SDMN	0	0	0	0	0	0	0	0	0
SDRF	0	0	0	0	1	9	4	0	14

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MINIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
ALHH	3	0	0	7	4	7	2	0	23
ALCL	7	1	0	0	0	0	0	0	8
ARSU	2	6	1	0	7	0	0	0	16
ARPO	5	0	1	0	1	2	7	0	16
ARPR	0	1	2	0	1	0	0	0	4
CACE	2	0	2	0	1	10	0	0	15
CADE	6	0	0	0	1	0	5	0	12
CANE	2	4	0	1	5	1	0	0	13
CODE	22	0	0	0	0	0	0	0	22
FLCL	1	15	0	0	0	0	0	0	16
GAOU	6	0	0	2	2	9	6	0	25
GAHA	9	8	0	0	2	0	0	0	19
GAMI	18	4	2	0	1	4	6	0	35
IAFA	9	0	1	2	4	0	0	0	16
IACO	0	4	0	1	1	8	0	1	15
IDAS	13	5	0	0	0	0	0	0	18
IDOA	1	0	0	3	7	0	0	0	11
IDPO	24	0	0	0	0	1	0	0	25
INRV	0	3	0	0	0	0	13	0	16
INCC	0	0	0	0	0	0	0	0	0
ILAN	12	2	2	1	0	0	0	0	17
ILGR	1	0	5	0	0	5	0	0	11
ILLH	12	1	0	0	0	0	0	0	13
ILWA	0	0	0	0	0	1	0	0	1
ILMA	12	8	0	0	0	10	0	0	30
ILML	12	2	1	0	1	0	0	0	16
ILPA	2	0	3	0	0	1	0	0	6
ILSP	12	1	0	0	0	0	0	0	13
ILMC	14	3	3	0	0	0	3	0	23
KACS	0	0	0	0	0	0	0	0	0
KYGE	0	2	0	0	4	1	0	0	7
KYIR	0	0	0	3	0	0	0	0	3

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MINIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
KYLF	0	0	1	0	1	0	1	0	3
KYSV	1	0	1	0	0	0	1	0	3
KYWB	4	1	0	6	1	15	0	0	27
LAMV	0	2	1	3	0	4	0	0	10
LAPD	0	1	3	0	3	2	1	0	10
MDWS	8	2	1	0	0	0	0	0	11
MEEP	0	0	0	3	0	0	0	0	3
MEFA	1	1	0	0	5	0	0	1	8
MIAL	0	0	3	0	0	0	10	1	14
MNPI	2	1	0	0	1	0	0	1	5
MNGM	0	0	0	0	0	0	0	0	0
MNPD	2	0	0	0	0	0	0	0	2
MNSL	1	3	0	0	0	0	1	0	5
MNPA	4	0	3	0	1	0	0	0	8
MNLL	10	1	0	0	0	0	0	0	11
MOAC	3	29	0	1	1	0	0	0	34
MOHA	0	1	0	0	0	4	0	0	5
MOLA	0	0	0	0	0	1	0	0	1
MOMH	1	10	10	0	1	0	0	0	22
MOAR	0	5	0	0	0	6	0	0	11
MOBR	0	0	0	0	0	1	0	0	1
MOLS	6	1	3	0	0	1	1	0	12
MOST	0	0	0	0	0	0	0	0	0
MOUN	0	0	0	0	0	0	0	0	0
MSBT	1	0	0	0	1	0	4	0	6
MSPT	0	4	0	1	0	0	0	0	5
MSSC	17	1	4	0	0	0	0	0	22
MTGL	11	7	3	0	3	0	0	0	24
NCSP	2	0	0	0	0	0	3	11	16
NDAM	2	0	0	0	15	0	0	0	17
NDNP	12	0	0	0	0	2	0	0	14
NHBE	6	4	7	1	0	2	1	0	21
NJBE	3	0	2	2	2	3	0	0	12
NJCB	0	0	0	0	1	0	0	0	1
NJFL	1	0	0	0	0	0	1	0	2
NMFB	0	5	23	0	0	0	7	0	35
NYAN	12	8	0	0	3	2	0	0	25
NYHE	2	5	0	0	0	0	1	0	8
NYLO	3	8	0	0	0	0	0	0	11
NYML	4	0	4	0	1	0	0	0	9
OHPH	1	15	0	0	0	1	0	0	17
OHMP	2	0	0	0	0	0	1	0	3
OKKF	0	0	1	4	0	0	2	0	7
ORHR	3	4	6	1	0	0	0	0	14
SCBV	0	3	5	0	2	3	0	0	13
SCKI	6	2	1	0	0	0	0	0	9
SCSV	0	0	4	0	0	0	0	0	4
SCYE	1	5	0	0	0	0	8	0	14
TNDO	21	7	0	1	0	0	0	0	29
TNRV	0	0	0	2	6	3	1	0	12
TNLB	0	0	0	0	0	0	0	0	0
TXBL	8	0	18	0	0	0	0	0	26
TXLL	19	0	0	1	0	6	0	0	26
TXBA	0	1	0	0	2	0	0	0	3
TXDA	6	3	2	0	0	0	0	0	11
TXHA	0	0	0	0	11	0	0	0	11
UTCO	0	0	0	0	0	0	0	0	0
UTFI	0	0	0	0	0	0	0	0	0
UTMA	23	0	0	0	0	1	0	0	24
UTHE	0	0	0	1	0	3	0	0	4
UTDE	2	3	0	0	0	0	0	0	5
UTLE	0	4	0	0	0	4	0	0	8
VABG	2	0	1	0	0	3	0	0	6
VACO	6	0	3	0	1	0	3	0	13
VAHS	1	7	0	0	0	1	1	0	10

NUMBER OF ESTIMATED MONTHS, BY DECADE -- MEAN MINIMUM TEMPERATURE

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
WADA	23	1	1	0	0	0	0	0	25
WADL	0	1	0	0	0	0	0	0	1
WIME	0	0	0	7	0	1	0	0	8
WIOC	0	3	3	0	0	0	6	0	12
WINE	3	6	0	1	10	2	0	0	22
WVGV	4	0	0	0	4	0	0	0	8
WVWB	1	6	0	0	0	0	0	0	7
WYYP	0	0	0	0	4	1	6	0	11
COCW	0	0	0	0	0	0	0	0	0
IAHU	1	13	0	0	0	0	0	1	15
IALD	1	0	0	1	0	0	0	0	2
IAMA	0	0	0	0	0	0	18	1	19
IARC	2	5	1	0	0	0	1	0	9
KACO	0	0	0	0	0	0	0	0	0
KAHA	0	0	0	0	0	0	0	0	0
KAHD	0	0	0	0	0	0	0	0	0
KAPH	0	0	0	0	0	0	0	0	0
MNMI	0	0	0	0	0	0	0	0	0
MOCD	1	7	0	0	1	0	0	0	9
MOOR	0	0	4	0	0	0	1	0	5
NEAU	0	1	0	0	16	0	1	0	18
NEBB	18	10	0	0	0	1	2	0	31
NEBC	0	9	3	0	0	0	5	0	17
NEBR	0	2	0	0	0	1	0	0	3
NECR	2	0	0	2	0	2	0	0	6
NEFA	0	0	1	0	2	9	1	1	14
NEGT	4	1	0	0	0	0	0	0	5
NEGV	1	3	0	0	0	0	0	0	4
NEHA	6	0	0	0	0	0	1	0	7
NEHS	3	2	0	0	0	1	9	0	15
NEIM	0	1	2	0	0	0	0	0	3
NEKI	4	0	6	0	2	3	0	0	15
NELC	4	6	13	1	0	2	0	0	26
NEMA	0	4	10	0	0	1	0	0	15
NEMI	0	2	4	2	0	0	0	0	8
NENL	1	0	0	0	0	3	4	0	8
NESP	0	0	0	0	0	0	0	0	0
NEVA	0	0	0	0	0	0	0	0	0
NEWA	0	10	0	1	3	2	0	0	16
SDAC	0	0	0	0	1	2	6	0	9
SDCL	0	0	0	0	0	0	0	0	0
SDFA	0	0	0	0	0	0	0	0	0
SDFB	0	0	0	0	0	0	1	0	1
SDMB	0	0	0	0	0	4	1	0	5
SDME	0	0	0	0	0	0	0	0	0
SDMN	0	0	0	0	0	0	0	0	0
SDRF	0	0	0	0	1	9	4	0	14

NUMBER OF ESTIMATED MONTHS, BY DECADE -- TOTAL PRECIPITATION

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
ALHH	6	0	0	1	2	2	0	0	11
ALCL	8	1	0	0	0	0	0	0	9
ARSU	1	10	1	0	0	0	1	0	13
ARPO	3	0	0	0	0	0	0	0	3
ARPR	2	0	3	0	0	0	0	0	5
CACE	0	0	0	0	0	9	0	0	9

NUMBER OF ESTIMATED MONTHS, BY DECADE -- TOTAL PRECIPITATION

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
CADE	7	5	0	0	0	1	0	0	13
CANE	0	0	0	0	0	0	0	0	0
CODE	20	1	0	0	0	0	0	0	21
FLCL	0	10	0	0	3	1	0	0	14
GAOU	0	0	0	1	0	0	1	0	2
GAHA	10	1	0	0	0	1	0	0	12
GAMI	10	2	0	0	1	1	5	1	20
IAFA	11	0	1	1	3	0	0	0	16
IACO	0	2	0	0	0	5	0	1	8
IDAS	9	6	0	0	0	0	0	0	15
IDOA	0	0	0	0	0	0	0	0	0
IDPD	2	0	0	0	0	0	0	0	2
INRV	0	2	0	0	0	0	13	0	15
INCC	1	0	0	0	0	0	0	0	1
ILAN	0	3	3	0	0	0	0	0	6
ILGR	0	2	6	0	1	12	0	1	22
ILLH	0	1	1	0	0	0	0	0	2
ILWA	0	2	3	0	0	0	0	0	5
ILMA	0	9	0	0	0	8	0	0	17
ILML	1	3	1	0	0	1	0	0	6
ILPA	2	0	9	4	0	1	0	0	16
ILSP	0	1	0	0	0	0	0	0	1
ILMC	2	3	6	0	0	0	0	0	11
KACS	0	0	0	0	0	0	0	0	0
KYGB	0	0	0	0	2	1	0	0	3
KYIR	3	0	0	5	0	0	2	0	10
KYLF	1	0	1	0	1	0	0	0	3
KYSV	1	0	3	0	0	1	0	0	5
KYWE	2	0	0	4	1	7	0	0	14
LAMV	0	1	0	1	0	0	0	0	2
LAPD	0	1	0	1	3	0	0	0	5
MDWS	10	3	4	0	0	0	8	5	30
MEEP	0	0	0	0	0	0	0	0	0
MEFA	1	0	0	0	1	0	0	1	3
MIAL	22	17	0	0	0	0	5	1	45
MNPI	0	0	0	0	0	2	0	0	2
MNGM	0	0	0	0	0	3	0	0	3
MNPO	0	0	0	0	0	0	0	0	0
MNSL	0	1	0	0	0	0	0	0	1
MNPA	2	0	3	0	1	2	0	0	8
MNLL	3	0	0	0	0	0	0	0	3
MOAC	3	25	0	0	0	0	0	0	28
MOHA	0	1	0	0	0	3	0	0	4
MOLA	0	0	0	0	0	0	0	0	0
MOMH	0	10	10	0	0	0	0	0	20
MOAR	0	0	0	0	0	6	0	0	6
MOBR	0	0	0	0	0	0	0	0	0
MOLS	6	0	4	0	0	0	1	0	11
MOST	0	0	0	0	0	0	0	0	0
MOUN	1	0	0	0	0	0	0	0	1
MSBT	0	0	0	0	0	1	0	0	1
MSPT	1	10	1	0	0	1	0	0	13
MSSC	9	2	2	1	0	0	0	0	14
MTGL	9	4	4	0	2	1	0	0	20
NCSP	2	0	0	0	0	0	4	11	17
NDAM	1	2	0	0	15	0	0	0	18
NDNP	0	0	0	0	0	0	0	0	0
NHBE	0	0	8	0	0	0	0	0	8
NJBE	2	2	0	2	0	0	0	0	6
NJCB	0	0	1	0	0	0	0	0	1
NJFL	0	0	1	0	0	0	1	0	2

NUMBER OF ESTIMATED MONTHS, BY DECADE -- TOTAL PRECIPITATION

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
NMFB	0	0	15	0	0	0	2	0	17
NYAN	14	10	0	0	2	1	0	0	27
NYHE	1	7	0	0	0	0	1	1	10
NYLO	2	6	0	1	0	0	0	0	9
NYML	3	0	1	0	0	0	1	0	5
OHPH	1	0	0	0	0	1	0	1	3
OHMP	0	0	0	0	0	0	0	0	0
OKKF	0	0	0	0	0	0	2	0	2
ORHR	3	0	2	9	8	0	0	0	22
SCBV	0	0	4	1	4	3	2	0	14
SCKI	0	0	0	1	0	1	2	1	5
SCSV	0	0	3	0	1	4	2	0	10
SCYE	1	0	0	0	1	1	4	0	7
TNDO	25	4	0	0	0	0	0	0	29
TNRV	0	0	0	0	0	0	1	0	1
TNLB	0	0	0	1	0	0	0	0	1
TXBL	1	0	0	0	2	0	0	0	3
TXLL	5	0	0	1	0	0	0	0	6
TXBA	0	0	0	0	2	1	0	0	3
TXDA	6	5	2	0	0	1	0	0	14
TXHA	1	0	2	0	15	2	0	0	20
UTCO	0	1	0	0	0	0	0	0	1
UTFI	0	0	0	0	0	0	0	0	0
UTMA	4	0	0	0	0	0	0	0	4
UTHE	1	0	0	0	0	0	0	0	1
UTDE	0	3	0	0	0	0	0	0	3
UTLE	0	4	0	0	0	0	0	0	4
VABG	1	0	1	0	0	7	0	0	9
VACC	1	0	0	1	1	1	0	0	4
VAHS	2	4	0	0	4	0	1	0	11
WADA	22	1	1	0	0	0	0	0	24
WADL	0	0	2	3	0	0	0	0	5
WIME	0	0	1	3	0	0	0	0	4
WIDC	0	8	4	0	2	4	9	0	27
WINE	2	8	0	1	8	0	0	0	19
WVGV	3	0	0	0	4	1	0	0	8
WVWB	0	0	0	0	2	8	2	0	12
WYYP	0	0	0	0	0	0	4	0	4
COCW	0	0	0	0	0	0	0	0	0
IAHU	0	0	0	0	0	0	0	0	0
IALO	0	0	0	0	0	0	0	0	0
IAMA	0	0	0	0	0	0	0	0	0
IARC	0	0	0	0	0	0	0	0	0
KACO	0	0	1	0	4	0	0	0	5
KAHA	9	0	0	0	0	0	0	0	9
KAHO	0	0	0	0	0	0	0	0	0
KAPH	26	0	2	0	0	0	0	0	28
MNMI	2	0	0	0	0	0	0	0	2
MOCC	1	7	0	0	0	0	0	0	8
MOOR	0	0	0	0	0	0	0	0	0
NEAU	0	1	0	0	0	1	0	0	2
NEBB	2	6	0	0	0	0	0	0	8
NEBC	0	8	3	0	0	0	0	0	11
NEBR	0	2	0	0	0	0	0	0	2
NECR	0	0	3	1	0	0	0	0	4
NEFA	0	0	0	0	1	1	0	0	2
NEGT	1	0	0	0	0	0	0	0	1
NEGV	0	3	0	0	0	0	0	0	3
NEHA	6	0	0	0	0	0	0	0	6
NEHS	2	0	0	0	0	0	0	0	2
NEIM	0	0	1	0	0	0	0	0	1
NEKI	3	0	6	0	0	0	0	0	9
NELC	0	2	17	0	0	0	0	0	19
NEMA	2	2	2	0	0	0	0	0	6
NEMI	0	1	0	2	4	0	0	0	7

NUMBER OF ESTIMATED MONTHS, BY DECADE -- TOTAL PRECIPITATION

STN	1900 1909	1910 1919	1920 1929	1930 1939	1940 1949	1950 1959	1960 1979	1970	TOTEST
NENL	0	0	0	0	0	0	0	0	0
NESP	0	0	0	0	0	0	0	0	0
NEVA	0	0	0	0	0	0	0	0	0
NEWA	0	4	0	0	2	0	0	0	6
SDAC	0	0	2	0	0	2	0	0	4
SDCL	2	3	11	0	11	0	0	0	27
SDFA	0	0	0	0	0	0	0	0	0
SDFB	1	0	0	0	0	0	0	0	1
SDMB	5	0	1	0	0	1	0	0	7
SDME	8	0	2	0	0	0	0	0	10
SDMN	0	12	4	0	1	0	0	0	17
SDRF	0	2	1	1	0	0	0	0	4

APPENDIX B

Pearson correlation coefficients for regression of each station's mean, maximum, and minimum annual temperature and total precipitation against the overall mean of the U.S. for each variable.

	STATION NUMBER	STATION	MEAN TEMP.	MAX	MIN	TOTAL PPT
1.	82	Highland Home, AL	0.14	0.62	0.58	0.53
2.	81	Clanton, AL	0.26	0.52	0.57	0.39
3.	59	Subiaco, AR	0.62	0.73	0.72	0.66
4.	58	Pocahontas, AR	0.56	0.71	0.73	0.59
5.	60	Prescott, AR	0.64	0.67	0.72	0.50
6.	4	Cedarville, CA	0.11	0.27	0.30	0.12
7.	6	Denair, CA	0.12	0.16	0.00	0.29
8.	5	Nevada City, CA	0.25	0.10	0.16	0.09
9.	18	Delta, CO	0.40	0.49	0.37	0.52
10.	90	Clermont, FL	0.00	0.26	0.24	0.28
11.	85	Quitman, GA	0.25	0.45	0.49	0.32
12.	84	Hawkinsville, GA	0.10	0.58	0.50	0.51
13.	83	Millen, GA	0.10	0.59	0.59	0.45
14.	43	Fayette, IA	0.52	0.91	0.85	0.90
15.	46	Corydon, IA	0.57	0.87	0.78	0.86
16.	8	Ashton, ID	0.14	0.38	0.35	0.35
17.	9	Oakley, ID	0.26	0.33	0.35	0.24
18.	7	Porthill, ID	0.26	0.33	0.32	0.25
19.	92	Rockville, IN	0.37	0.86	0.74	0.89
20.	93	Cambridge City, IN	0.37	0.84	0.79	0.79
21.	74	Anna, IL	0.45	0.77	0.65	0.80
22.	70	Griggsville, IL	0.49	0.88	0.86	0.84
23.	69	La Harpe, IL	0.52	0.93	0.86	0.92
24.	68	Walnut, IL	0.43	0.91	0.86	0.93
25.	67	Marengo, IL	0.47	0.89	0.81	0.86
26.	73	McLeansboro, IL	0.45	0.88	0.85	0.75
27.	71	Palestine, IL	0.50	0.85	0.86	0.75
28.	72	Sparta, IL	0.53	0.90	0.88	0.89
29.	66	Mt. Carroll, IL	0.51	0.90	0.85	0.83
30.	27	Columbus, KA	0.67	0.86	0.82	0.87
31.	97	Greensburg, KY	0.31	0.77	0.79	0.64
32.	95	Irvington, KY	0.47	0.78	0.76	0.58
33.	96	Leitchfield, KY	0.41	0.85	0.78	0.81
34.	94	Shelbyville, KY	0.46	0.74	0.68	0.68
35.	98	Williamsburg, KY	0.22	0.69	0.63	0.58
36.	62	Melville, LA	0.22	0.65	0.43	0.53
37.	61	Plain Dealing, LA	0.52	0.67	0.66	0.64
38.	114	Woodstock, MD	0.20	0.46	0.52	0.27
39.	117	Eastport, ME	0.08	0.34	0.30	0.74
40.	116	Farmington, ME	-0.09	0.57	0.50	0.36
41.	91	Allegan, MI	0.13	0.75	0.61	0.24
42.	38	Pine River Dam, MN	0.44	0.59	0.56	0.58
43.	40	Grand Meadow, MN	0.51	0.82	0.70	0.81
44.	36	Pokegama Dam, MN	0.39	0.62	0.55	0.63
45.	37	Sandy Lake Dam, MN	0.40	0.62	0.52	0.70
46.	34	Park Rapids, MN	0.48	0.63	0.65	0.59
47.	35	Leach Lake, MN	0.56	0.66	0.58	0.62
48.	54	Appleton City, MO	0.69	0.85	0.72	0.81
49.	53	Harrisonville, MO	0.64	0.70	0.77	0.58
50.	55	Lamar, MO	0.63	0.70	0.72	0.54
51.	57	Marble Hill, MO	0.46	0.77	0.76	0.60
52.	56	Arcadia, MO	0.54	0.58	0.56	0.51
53.	52	Brunswick, MO	0.56	0.82	0.80	0.75
54.	51	Louisiana Starks Nursery, MO	0.39	0.84	0.72	0.86
55.	50	Steffenville, MO	0.31	0.84	0.71	0.86
56.	48	Unionville, MO	0.50	0.88	0.85	0.68
57.	78	Batesville, MS	0.67	0.63	0.66	0.53
58.	79	Pontotoc, MS	0.25	0.76	0.70	0.66
59.	80	State College, MS	0.42	0.63	0.56	0.56
60.	16	Glendive, MT	0.39	0.61	0.59	0.59

	STATION NUMBER	STATION	MEAN TEMP.	MAX	MIN	TOTAL PPT
61.	106	Southport, NC	0.15	0.62	0.38	0.52
62.	22	Amenia, ND	0.53	0.61	0.58	0.52
63.	21	Napoleon, ND	0.24	0.73	0.78	0.63
64.	115	Bethlehem, NH	0.01	0.52	0.50	0.47
65.	112	Belvidere, NJ	0.16	0.62	0.61	0.59
66.	111	Charlottesburg, NJ	0.11	0.62	0.61	0.45
67.	113	Flemington, NJ	0.17	0.66	0.66	0.56
68.	20	Fort Bayard, NM	0.27	0.21	0.26	0.17
69.	109	Angelica, NY	0.31	0.76	0.70	0.67
70.	108	Hemlock, NY	0.11	0.61	0.62	0.49
71	107	Lowville, NY	0.33	0.48	0.50	0.37
72.	110	Mohonk Lake, NY	-0.01	0.54	0.47	0.44
73.	100	Philo, OH	0.29	0.86	0.77	0.79
74.	99	Millport, OH	0.14	0.77	0.68	0.79
75.	28	Kingfisher, OK	0.61	0.74	0.67	0.80
76.	3	Hood River, OR	0.19	0.10	0.15	0.45
77.	86	Blackville, SC	0.16	0.50	0.36	0.52
78.	87	Kingstree, SC	0.15	0.56	0.67	0.38
79.	88	Summerville, SC	0.26	0.56	0.62	0.36
80.	89	Yemmassee 4W, SC	0.35	0.62	0.64	0.39
81.	75	Dover, TN	0.53	0.61	0.48	0.71
82.	77	Rogersville, TN	0.24	0.58	0.62	0.52
83.	76	Lewisberg, TN	0.40	0.61	0.61	0.58
84.	31	Blanco, TX	0.32	0.54	0.57	0.26
85.	30	Llano, TX	0.23	0.40	0.45	0.26
86.	29	Ballinger, TX	0.38	0.50	0.41	0.52
87.	33	Danevang, TX	0.38	0.33	0.19	0.39
88.	32	Hallettsville, TX	0.24	0.13	0.19	0.15
89.	10	Corinne, UT	0.32	0.27	0.30	0.20
90.	15	Fillmore, UT	0.42	0.34	0.12	0.47
91.	14	Manti, UT	0.39	0.24	0.10	0.38
92.	11	Heber, UT	0.28	0.40	0.44	0.28
93.	13	Deseret, UT	0.36	0.36	0.33	0.33
94.	12	Levan, UT	0.39	0.41	0.42	0.32
95.	105	Burkes Garden, VA	0.25	0.64	0.62	0.60
96.	104	Columbia, VA	0.21	0.75	0.66	0.54
97.	103	Hot Springs, VA	0.18	0.58	0.46	0.60
98.	2	Dayton, WA	0.31	0.14	0.22	0.05
99.	1	Olga, WA	-0.06	0.14	0.17	0.07
100.	63	Medford, WI	0.34	0.64	0.46	0.73
101.	64	Oconto, WI	0.45	0.67	0.56	0.73
102.	65	Neillsville, WI	0.18	0.76	0.67	0.76
103.	102	Glenville, WV	0.20	0.62	0.50	0.60
104.	101	Wellsburg, WV	0.22	0.76	0.65	0.24
105.	17	Yellowstone Park, WY	0.16	0.35	0.30	0.38
106.	19	Cheyenne Wells, CO	0.61	0.70	0.69	0.62
107.	41	Humbolt, IA	0.53	0.83	0.76	0.78
108.	44	Logan, IA	0.70	0.90	0.83	0.84
109.	45	Mt. Ayr, IA	0.54	0.90	0.86	0.89
110.	42	Rockwell City, IA	0.58	0.88	0.83	0.88
111.	23	Colby, KA	0.61	0.79	0.70	0.76
112.	26	Ft. Hays, KA	0.69	0.84	0.80	0.83
113.	25	Horton, KA	0.57	0.89	0.87	.80
114.	24	Phillipsburg, KA	0.68	0.79	0.76	0.76
115.	39	Milan, MN	0.37	0.86	0.79	0.84
116.	46	Conception, MO	0.57	0.87	0.78	0.86
117.	49	Oregon, MO	0.58	0.88	0.89	0.77
118.	143	Auburn, NE	0.57	0.90	0.88	0.84
119.	133	Broken Bow, NE	0.63	0.81	0.78	0.68
120.	139	Beaver City, NE	0.65	0.85	0.73	0.80
121.	131	Bridgeport, NE	0.61	0.66	0.71	0.48

	STATION NUMBER	STATION	MEAN TEMP.	MAX	MIN	TOTAL PPT
122.	143	Crete, NE	0.59	0.89	0.82	0.88
123.	141	Fairmont, NE	0.67	0.78	0.76	0.78
124.	135	Gothenburg, NE	0.58	0.81	0.73	0.71
125.	142	Geneva, NE	0.69	0.83	0.72	0.80
126.	128	Hartington, NE	0.61	0.84	0.78	0.85
127.	127	Hay Springs, NE	0.62	0.72	0.78	0.49
128.	138	Imperial, NE	0.52	0.74	0.74	0.59
129.	132	Kimball, NE	0.59	0.68	0.72	0.52
130.	136	Loup City, NE	0.55	0.83	0.85	0.74
131.	130	Madison, NE	0.63	0.86	0.81	0.79
132.	140	Minden, NE	0.68	0.88	0.87	0.79
133.	134	North Loup, NE	0.52	0.80	0.80	0.58
134.	137	St. Paul, NE	0.68	0.85	0.79	0.79
135.	126	Valentine, NE	0.44	0.86	0.81	0.80
136.	129	Wakefield, NE	0.66	0.90	0.89	0.87
137.	124	Academy, SD	0.54	0.76	0.73	0.68
138.	122	Clark, SD	0.42	0.82	0.75	0.76
139.	120	Faulkton, SD	0.54	0.67	0.70	0.59
140.	123	Forestburg, SD	0.58	0.82	0.69	0.81
141.	119	Milbank, SD	0.45	0.29	0.76	0.73
142.	118	Mellette, SD	0.42	0.85	0.79	0.82
143.	125	Menno, SD	0.56	0.85	0.79	0.84
144.	121	Redfield, SD	0.47	0.82	0.78	0.76

APPENDIX C

The Probability Integral

The probability integral

Values of A, the portion of the area under the normal frequency curve to the left of the ordinate distant x from the mean. Total area = 1,000 ; σ is the standard deviation of the normal distribution.

x/σ	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
−4	0·032	0·021	0·013	0·009	0·0054	0·0034	0·0021	0·0013	0·0008	0·0005
−3	1·35	0·97	0·69	0·48	0·34	0·23	0·16	0·11	0·07	0·05
−2	22·8	17·9	13·9	10·7	8·2	6·2	4·7	3·5	2·56	1·87
	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
−1·9	29	28	27	27	26	26	25	24	24	23
−1·8	36	35	34	34	33	32	31	31	30	29
−1·7	45	44	43	42	41	40	39	38	38	37
−1·6	55	54	53	52	51	49	48	47	46	46
−1·5	67	66	64	63	62	61	59	58	57	56
−1·4	81	79	78	76	75	74	72	71	69	68
−1·3	97	95	93	92	90	89	87	85	84	82
−1·2	115	113	111	109	107	106	104	102	100	99
−1·1	136	133	131	129	127	125	123	121	119	117
−1·0	159	156	154	152	149	147	145	142	140	138
−0·9	184	181	179	176	174	171	169	166	164	161
−0·8	212	209	206	203	200	198	195	192	189	187
−0·7	242	239	236	233	230	227	224	221	218	215
−0·6	274	271	268	264	261	258	255	251	248	245
−0·5	309	305	302	298	295	291	288	284	281	278
−0·4	345	341	337	334	330	326	323	319	316	312
−0·3	382	378	374	371	367	363	359	356	352	348
−0·2	421	417	413	409	405	401	397	394	390	386
−0·1	460	456	452	448	444	440	436	433	429	425
−0·0	500	496	492	488	484	480	476	472	468	464
+0·0	500	504	508	512	516	520	524	528	532	536
0·1	540	544	548	552	556	560	564	567	571	575
0·2	579	583	587	591	595	599	603	606	610	614
0·3	618	622	626	629	633	637	641	644	648	652
0·4	655	659	663	666	670	674	677	681	684	688
0·5	691	695	698	702	705	709	712	716	719	722
0·6	726	729	732	736	739	742	745	749	752	755
0·7	758	761	764	767	770	773	776	779	782	785
0·8	788	791	794	797	800	802	805	808	811	813
0·9	816	819	821	824	826	829	831	834	836	839
1·0	841	844	846	848	851	853	855	858	860	862
1·1	864	867	869	871	873	875	877	879	881	883
1·2	885	887	889	891	893	894	896	898	900	901
1·3	903	905	907	908	910	911	913	915	916	918
1·4	919	921	922	924	925	926	928	929	931	932
1·5	933	934	936	937	938	939	941	942	943	944
1·6	945	946	947	948	949	951	952	953	954	954
1·7	955	956	957	958	959	960	961	962	962	963
1·8	964	965	966	966	967	968	969	969	970	971
1·9	971	972	973	973	974	974	975	976	976	977
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
2	977·2	982·1	986·1	989·3	991·8	993·8	995·3	996·5	997·4	998·1
3	998·7	999·0	999·3	999·5	999·7	999·8	999·8	999·9	999·9	1000·0

(Area to left of $+x$) = 1,000 − (area to left of $-x$) ; to obtain the area "to the right", reverse the sign of x/σ.

APPENDIX D

t - Table

Distribution of "Students" t,
Given the Limiting Probability*

n	.1	.05	.01	.001
1	6.314	12.706	63.657	636.619
2	2.920	4.303	9.925	31.598
3	2.353	3.182	5.841	12.941
4	2.132	2.776	4.604	8.610
5	2.015	2.571	4.032	6.859
6	1.943	2.447	3.707	5.959
7	1.895	2.365	3.499	5.405
8	1.860	2.306	3.355	5.041
9	1.833	2.262	3.250	4.781
10	1.812	2.228	3.169	4.587
11	1.796	2.201	3.106	4.437
12	1.782	2.179	3.055	4.318
13	1.771	2.160	3.012	4.221
14	1.761	2.145	2.977	4.140
15	1.753	2.131	2.947	4.073
16	1.746	2.120	2.921	4.015
17	1.740	2.110	2.898	3.965
18	1.734	2.101	2.878	3.922
19	1.729	2.093	2.861	3.883
20	1.725	2.086	2.845	3.850
21	1.721	2.080	2.831	3.819
22	1.717	2.074	2.819	3.792
23	1.714	2.069	2.807	3.767
24	1.711	2.064	2.797	3.745
25	1.708	2.060	2.787	3.725
26	1.706	2.056	2.779	3.707
27	1.703	2.052	2.771	3.690
28	1.701	2.048	2.763	3.674
29	1.699	2.045	2.756	3.659
30	1.697	2.042	2.750	3.646
40	1.684	2.021	2.704	3.551
60	1.671	2.000	2.660	3.460
120	1.658	1.980	2.617	3.373
∞	1.645	1.960	2.576	3.291

*Abridged from Table III of Fisher and Yates "Statistical Tables for Biological, Agricultural, and Medical Research," published by Oliver and Boyd Ltd., Edinburgh, by permission of the authors and publishers.

APPENDIX E

F - Table

Limiting Values of F

5% (ROMAN TYPE) AND 1% (ITALICS) POINTS FOR THE DISTRIBUTION OF F*

n_2	n_1 degrees of freedom (for greater mean square)																							
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
1	161 *4,052*	200 *4,999*	216 *5,403*	225 *5,625*	230 *5,764*	234 *5,859*	237 *5,928*	239 *5,981*	241 *6,022*	242 *6,056*	243 *6,082*	244 *6,106*	245 *6,142*	246 *6,169*	248 *6,208*	249 *6,234*	250 *6,258*	251 *6,286*	252 *6,302*	253 *6,323*	253 *6,334*	254 *6,352*	254 *6,361*	254 *6,366*
2	18.51 *98.49*	19.00 *99.01*	19.16 *99.17*	19.25 *99.25*	19.30 *99.30*	19.33 *99.33*	19.36 *99.34*	19.37 *99.36*	19.38 *99.38*	19.39 *99.40*	19.40 *99.41*	19.41 *99.42*	19.42 *99.43*	19.43 *99.44*	19.44 *99.45*	19.45 *99.46*	19.46 *99.47*	19.47 *99.48*	19.47 *99.48*	19.48 *99.49*	19.49 *99.49*	19.49 *99.49*	19.50 *99.50*	19.50 *99.50*
3	10.13 *34.12*	9.55 *30.81*	9.28 *29.46*	9.12 *28.71*	9.01 *28.24*	8.94 *27.91*	8.88 *27.67*	8.84 *27.49*	8.81 *27.34*	8.78 *27.23*	8.76 *27.13*	8.74 *27.05*	8.71 *26.92*	8.69 *26.83*	8.66 *26.69*	8.64 *26.60*	8.62 *26.50*	8.60 *26.41*	8.58 *26.35*	8.57 *26.27*	8.56 *26.23*	8.54 *26.18*	8.54 *26.14*	8.53 *26.12*
4	7.71 *21.20*	6.94 *18.00*	6.59 *16.69*	6.39 *15.98*	6.26 *15.52*	6.16 *15.21*	6.09 *14.98*	6.04 *14.80*	6.00 *14.66*	5.96 *14.54*	5.93 *14.45*	5.91 *14.37*	5.87 *14.24*	5.84 *14.15*	5.80 *14.02*	5.77 *13.93*	5.74 *13.83*	5.71 *13.74*	5.70 *13.69*	5.68 *13.61*	5.66 *13.57*	5.65 *13.52*	5.64 *13.48*	5.63 *13.46*
5	6.61 *16.26*	5.79 *13.27*	5.41 *12.06*	5.19 *11.39*	5.05 *10.97*	4.95 *10.67*	4.88 *10.45*	4.82 *10.27*	4.78 *10.15*	4.74 *10.05*	4.70 *9.96*	4.68 *9.89*	4.64 *9.77*	4.60 *9.68*	4.56 *9.55*	4.53 *9.47*	4.50 *9.38*	4.46 *9.29*	4.44 *9.24*	4.42 *9.17*	4.40 *9.13*	4.38 *9.07*	4.37 *9.04*	4.36 *9.02*
6	5.99 *13.74*	5.14 *10.92*	4.76 *9.78*	4.53 *9.15*	4.39 *8.75*	4.28 *8.47*	4.21 *8.26*	4.15 *8.10*	4.10 *7.98*	4.06 *7.87*	4.03 *7.79*	4.00 *7.72*	3.96 *7.60*	3.92 *7.52*	3.87 *7.39*	3.84 *7.31*	3.81 *7.23*	3.77 *7.14*	3.75 *7.09*	3.72 *7.02*	3.71 *6.99*	3.69 *6.94*	3.68 *6.90*	3.67 *6.88*
7	5.59 *12.25*	4.74 *9.55*	4.35 *8.45*	4.12 *7.85*	3.97 *7.46*	3.87 *7.19*	3.79 *7.00*	3.73 *6.84*	3.68 *6.71*	3.63 *6.62*	3.60 *6.54*	3.57 *6.47*	3.52 *6.35*	3.49 *6.27*	3.44 *6.15*	3.41 *6.07*	3.38 *5.98*	3.34 *5.90*	3.32 *5.85*	3.29 *5.78*	3.28 *5.75*	3.25 *5.70*	3.24 *5.67*	3.23 *5.65*
8	5.32 *11.26*	4.46 *8.65*	4.07 *7.59*	3.84 *7.01*	3.69 *6.63*	3.58 *6.37*	3.50 *6.19*	3.44 *6.03*	3.39 *5.91*	3.34 *5.82*	3.31 *5.74*	3.28 *5.67*	3.23 *5.56*	3.20 *5.48*	3.15 *5.36*	3.12 *5.28*	3.08 *5.20*	3.05 *5.11*	3.03 *5.06*	3.00 *5.00*	2.98 *4.96*	2.96 *4.91*	2.94 *4.88*	2.93 *4.86*
9	5.12 *10.56*	4.26 *8.02*	3.86 *6.99*	3.63 *6.42*	3.48 *6.06*	3.37 *5.80*	3.29 *5.62*	3.23 *5.47*	3.18 *5.35*	3.13 *5.26*	3.10 *5.18*	3.07 *5.11*	3.02 *5.00*	2.98 *4.92*	2.93 *4.80*	2.90 *4.73*	2.86 *4.64*	2.82 *4.56*	2.80 *4.51*	2.77 *4.45*	2.76 *4.41*	2.73 *4.36*	2.72 *4.33*	2.71 *4.31*
10	4.96 *10.04*	4.10 *7.56*	3.71 *6.55*	3.48 *5.99*	3.33 *5.64*	3.22 *5.39*	3.14 *5.21*	3.07 *5.06*	3.02 *4.95*	2.97 *4.85*	2.94 *4.78*	2.91 *4.71*	2.86 *4.60*	2.82 *4.52*	2.77 *4.41*	2.74 *4.33*	2.70 *4.25*	2.67 *4.17*	2.64 *4.12*	2.61 *4.05*	2.59 *4.01*	2.56 *3.96*	2.55 *3.93*	2.54 *3.91*
11	4.84 *9.65*	3.98 *7.20*	3.59 *6.22*	3.36 *5.67*	3.20 *5.32*	3.09 *5.07*	3.01 *4.88*	2.95 *4.74*	2.90 *4.63*	2.86 *4.54*	2.82 *4.46*	2.79 *4.40*	2.74 *4.29*	2.70 *4.21*	2.65 *4.10*	2.61 *4.02*	2.57 *3.94*	2.53 *3.86*	2.50 *3.80*	2.47 *3.74*	2.45 *3.70*	2.42 *3.66*	2.41 *3.62*	2.40 *3.60*
12	4.75 *9.33*	3.88 *6.93*	3.49 *5.95*	3.26 *5.41*	3.11 *5.06*	3.00 *4.82*	2.92 *4.65*	2.85 *4.50*	2.80 *4.39*	2.76 *4.30*	2.72 *4.22*	2.69 *4.16*	2.64 *4.05*	2.60 *3.98*	2.54 *3.86*	2.50 *3.78*	2.46 *3.70*	2.42 *3.61*	2.40 *3.56*	2.36 *3.49*	2.35 *3.46*	2.32 *3.41*	2.31 *3.38*	2.30 *3.36*
13	4.67 *9.07*	3.80 *6.70*	3.41 *5.74*	3.18 *5.20*	3.02 *4.86*	2.92 *4.62*	2.84 *4.44*	2.77 *4.30*	2.72 *4.19*	2.67 *4.10*	2.63 *4.02*	2.60 *3.96*	2.55 *3.85*	2.51 *3.78*	2.46 *3.67*	2.41 *3.59*	2.38 *3.51*	2.34 *3.42*	2.32 *3.37*	2.28 *3.30*	2.26 *3.27*	2.24 *3.21*	2.22 *3.18*	2.21 *3.16*

*This table reproduced from G. W. Snedecor's "Statistical Methods" by permission of the author and his publishers. Calculated by G. W. Snedecor from Table VI of R. A. Fishers' "Statistical Methods for Research Works."

5% (ROMAN TYPE) AND 1% (ITALICS) POINTS FOR THE DISTRIBUTION OF F

n_2	n_1 degrees of freedom (for greater mean square)																							
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
14	4.60 *8.86*	3.74 *6.51*	3.34 *5.56*	3.11 *5.03*	2.96 *4.69*	2.85 *4.46*	2.77 *4.28*	2.70 *4.14*	2.65 *4.03*	2.60 *3.94*	2.56 *3.86*	2.53 *3.80*	2.48 *3.70*	2.44 *3.62*	2.39 *3.51*	2.35 *3.43*	2.31 *3.34*	2.27 *3.26*	2.24 *3.21*	2.21 *3.14*	2.19 *3.11*	2.16 *3.06*	2.14 *3.02*	2.13 *3.00*
15	4.54 *8.68*	3.68 *6.36*	3.29 *5.42*	3.06 *4.89*	2.90 *4.56*	2.79 *4.32*	2.70 *4.14*	2.64 *4.00*	2.59 *3.89*	2.55 *3.80*	2.51 *3.73*	2.48 *3.67*	2.43 *3.56*	2.39 *3.48*	2.33 *3.36*	2.29 *3.29*	2.25 *3.20*	2.21 *3.12*	2.18 *3.07*	2.15 *3.00*	2.12 *2.97*	2.10 *2.92*	2.08 *2.89*	2.07 *2.87*
16	4.49 *8.53*	3.63 *6.23*	3.24 *5.29*	3.01 *4.77*	2.85 *4.44*	2.74 *4.20*	2.66 *4.03*	2.59 *3.89*	2.54 *3.78*	2.49 *3.69*	2.45 *3.61*	2.42 *3.55*	2.37 *3.45*	2.33 *3.37*	2.28 *3.25*	2.24 *3.18*	2.20 *3.10*	2.16 *3.01*	2.13 *2.96*	2.09 *2.89*	2.07 *2.86*	2.04 *2.80*	2.02 *2.77*	2.01 *2.75*
17	4.45 *8.40*	3.59 *6.11*	3.20 *5.18*	2.96 *4.67*	2.81 *4.34*	2.70 *4.10*	2.62 *3.93*	2.55 *3.79*	2.50 *3.68*	2.45 *3.59*	2.41 *3.52*	2.38 *3.45*	2.33 *3.35*	2.29 *3.27*	2.23 *3.16*	2.19 *3.08*	2.15 *3.00*	2.11 *2.92*	2.08 *2.86*	2.04 *2.79*	2.02 *2.76*	1.99 *2.70*	1.97 *2.67*	1.96 *2.65*
18	4.41 *8.28*	3.55 *6.01*	3.16 *5.09*	2.93 *4.58*	2.77 *4.25*	2.66 *4.01*	2.58 *3.85*	2.51 *3.71*	2.46 *3.60*	2.41 *3.51*	2.37 *3.44*	2.34 *3.37*	2.29 *3.27*	2.25 *3.19*	2.19 *3.07*	2.15 *3.00*	2.11 *2.91*	2.07 *2.83*	2.04 *2.78*	2.00 *2.71*	1.98 *2.68*	1.95 *2.62*	1.93 *2.59*	1.92 *2.57*
19	4.38 *8.18*	3.52 *5.93*	3.13 *5.01*	2.90 *4.50*	2.74 *4.17*	2.63 *3.94*	2.55 *3.77*	2.48 *3.63*	2.43 *3.52*	2.38 *3.43*	2.34 *3.36*	2.31 *3.30*	2.26 *3.19*	2.21 *3.12*	2.15 *3.00*	2.11 *2.92*	2.07 *2.84*	2.02 *2.76*	2.00 *2.70*	1.96 *2.63*	1.94 *2.60*	1.91 *2.54*	1.90 *2.51*	1.88 *2.49*
20	4.35 *8.10*	3.49 *5.85*	3.10 *4.94*	2.87 *4.43*	2.71 *4.10*	2.60 *3.87*	2.52 *3.71*	2.45 *3.56*	2.40 *3.45*	2.35 *3.37*	2.31 *3.30*	2.28 *3.23*	2.23 *3.13*	2.18 *3.05*	2.12 *2.94*	2.08 *2.86*	2.04 *2.77*	1.99 *2.69*	1.96 *2.63*	1.92 *2.56*	1.90 *2.53*	1.87 *2.47*	1.85 *2.44*	1.84 *2.42*
21	4.32 *8.02*	3.47 *5.78*	3.07 *4.87*	2.84 *4.37*	2.68 *4.04*	2.57 *3.81*	2.49 *3.65*	2.42 *3.51*	2.37 *3.40*	2.32 *3.31*	2.28 *3.24*	2.25 *3.17*	2.20 *3.07*	2.15 *2.99*	2.09 *2.88*	2.05 *2.80*	2.00 *2.72*	1.96 *2.63*	1.93 *2.58*	1.89 *2.51*	1.87 *2.47*	1.84 *2.42*	1.82 *2.38*	1.81 *2.36*
22	4.30 *7.94*	3.44 *5.72*	3.05 *4.82*	2.82 *4.31*	2.66 *3.99*	2.55 *3.76*	2.47 *3.59*	2.40 *3.45*	2.35 *3.35*	2.30 *3.26*	2.26 *3.18*	2.23 *3.12*	2.18 *3.02*	2.13 *2.94*	2.07 *2.83*	2.03 *2.75*	1.98 *2.67*	1.93 *2.58*	1.91 *2.53*	1.87 *2.46*	1.84 *2.42*	1.81 *2.37*	1.80 *2.33*	1.78 *2.31*
23	4.28 *7.88*	3.42 *5.66*	3.03 *4.76*	2.80 *4.26*	2.64 *3.94*	2.53 *3.71*	2.45 *3.54*	2.38 *3.41*	2.32 *3.30*	2.28 *3.21*	2.24 *3.14*	2.20 *3.07*	2.14 *2.97*	2.10 *2.89*	2.04 *2.78*	2.00 *2.70*	1.96 *2.62*	1.91 *2.53*	1.88 *2.48*	1.84 *2.41*	1.82 *2.37*	1.79 *2.32*	1.77 *2.28*	1.76 *2.26*
24	4.26 *7.82*	3.40 *5.61*	3.01 *4.72*	2.78 *4.22*	2.62 *3.90*	2.51 *3.67*	2.43 *3.50*	2.36 *3.36*	2.30 *3.25*	2.26 *3.17*	2.22 *3.09*	2.18 *3.03*	2.13 *2.93*	2.09 *2.85*	2.02 *2.74*	1.98 *2.66*	1.94 *2.58*	1.89 *2.49*	1.86 *2.44*	1.82 *2.36*	1.80 *2.33*	1.76 *2.27*	1.74 *2.23*	1.73 *2.21*
25	4.24 *7.77*	3.38 *5.57*	2.99 *4.68*	2.76 *4.18*	2.60 *3.86*	2.49 *3.63*	2.41 *3.46*	2.34 *3.32*	2.28 *3.21*	2.24 *3.13*	2.20 *3.05*	2.16 *2.99*	2.11 *2.89*	2.06 *2.81*	2.00 *2.70*	1.96 *2.62*	1.92 *2.54*	1.87 *2.45*	1.84 *2.40*	1.80 *2.32*	1.77 *2.29*	1.74 *2.23*	1.72 *2.19*	1.71 *2.17*
26	4.22 *7.72*	3.37 *5.53*	2.98 *4.64*	2.74 *4.14*	2.59 *3.82*	2.47 *3.59*	2.39 *3.42*	2.32 *3.29*	2.27 *3.17*	2.22 *3.09*	2.18 *3.02*	2.15 *2.96*	2.10 *2.86*	2.05 *2.77*	1.99 *2.66*	1.95 *2.58*	1.90 *2.50*	1.85 *2.41*	1.82 *2.36*	1.78 *2.28*	1.76 *2.25*	1.72 *2.19*	1.70 *2.15*	1.69 *2.13*

n_2	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
	n_1 degrees of freedom (for greater mean square)																							
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.30	2.25	2.20	2.16	2.13	2.08	2.03	1.97	1.93	1.88	1.84	1.80	1.76	1.74	1.71	1.68	1.67
	7.68	*5.49*	*4.60*	*4.11*	*3.79*	*3.56*	*3.39*	*3.26*	*3.14*	*3.06*	*2.98*	*2.93*	*2.83*	*2.74*	*2.63*	*2.55*	*2.47*	*2.38*	*2.33*	*2.25*	*2.21*	*2.16*	*2.12*	*2.10*
28	4.20	3.34	2.95	2.71	2.56	2.44	2.36	2.29	2.24	2.19	2.15	2.12	2.06	2.02	1.96	1.91	1.87	1.81	1.78	1.75	1.72	1.69	1.67	1.65
	7.64	*5.45*	*4.57*	*4.07*	*3.76*	*3.53*	*3.36*	*3.23*	*3.11*	*3.03*	*2.95*	*2.90*	*2.80*	*2.71*	*2.60*	*2.52*	*2.44*	*2.35*	*2.30*	*2.22*	*2.18*	*2.13*	*2.09*	*2.06*
29	4.18	3.33	2.93	2.70	2.54	2.43	2.35	2.28	2.22	2.18	2.14	2.10	2.05	2.00	1.94	1.90	1.85	1.80	1.77	1.73	1.71	1.68	1.65	1.64
	7.60	*5.42*	*4.54*	*4.04*	*3.73*	*3.50*	*3.33*	*3.20*	*3.08*	*3.00*	*2.92*	*2.87*	*2.77*	*2.68*	*2.57*	*2.49*	*2.41*	*2.32*	*2.27*	*2.19*	*2.15*	*2.10*	*2.06*	*2.03*
30	4.17	3.32	2.92	2.69	2.53	2.42	2.34	2.27	2.21	2.16	2.12	2.09	2.04	1.99	1.93	1.89	1.84	1.79	1.76	1.72	1.69	1.66	1.64	1.62
	7.56	*5.39*	*4.51*	*4.02*	*3.70*	*3.47*	*3.30*	*3.17*	*3.06*	*2.98*	*2.90*	*2.84*	*2.74*	*2.66*	*2.55*	*2.47*	*2.38*	*2.29*	*2.24*	*2.16*	*2.13*	*2.07*	*2.03*	*2.01*
32	4.15	3.30	2.90	2.67	2.51	2.40	2.32	2.25	2.19	2.14	2.10	2.07	2.02	1.97	1.91	1.86	1.82	1.76	1.74	1.69	1.67	1.64	1.61	1.59
	7.50	*5.34*	*4.46*	*3.97*	*3.66*	*3.42*	*3.25*	*3.12*	*3.01*	*2.94*	*2.86*	*2.80*	*2.70*	*2.62*	*2.51*	*2.42*	*2.34*	*2.25*	*2.20*	*2.12*	*2.08*	*2.02*	*1.98*	*1.96*
34	4.13	3.28	2.88	2.65	2.49	2.38	2.30	2.23	2.17	2.12	2.08	2.05	2.00	1.95	1.89	1.84	1.80	1.74	1.71	1.67	1.64	1.61	1.59	1.57
	7.44	*5.29*	*4.42*	*3.93*	*3.61*	*3.38*	*3.21*	*3.08*	*2.97*	*2.89*	*2.82*	*2.76*	*2.66*	*2.58*	*2.47*	*2.38*	*2.30*	*2.21*	*2.15*	*2.08*	*2.04*	*1.98*	*1.94*	*1.91*
36	4.11	3.26	2.86	2.63	2.48	2.36	2.28	2.21	2.15	2.10	2.06	2.03	1.98	1.93	1.87	1.82	1.78	1.72	1.69	1.65	1.62	1.59	1.56	1.55
	7.39	*5.25*	*4.38*	*3.89*	*3.58*	*3.35*	*3.18*	*3.04*	*2.94*	*2.86*	*2.78*	*2.72*	*2.62*	*2.54*	*2.43*	*2.35*	*2.26*	*2.17*	*2.12*	*2.04*	*2.00*	*1.94*	*1.90*	*1.87*
38	4.10	3.25	2.85	2.62	2.46	2.35	2.26	2.19	2.14	2.09	2.05	2.02	1.96	1.92	1.85	1.80	1.76	1.71	1.67	1.63	1.60	1.57	1.54	1.53
	7.35	*5.21*	*4.34*	*3.86*	*3.54*	*3.32*	*3.15*	*3.02*	*2.91*	*2.82*	*2.75*	*2.69*	*2.59*	*2.51*	*2.40*	*2.32*	*2.22*	*2.14*	*2.08*	*2.00*	*1.97*	*1.90*	*1.86*	*1.84*
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.07	2.04	2.00	1.95	1.90	1.84	1.79	1.74	1.69	1.66	1.61	1.59	1.55	1.53	1.51
	7.31	*5.18*	*4.31*	*3.83*	*3.51*	*3.29*	*3.12*	*2.99*	*2.88*	*2.80*	*2.73*	*2.66*	*2.56*	*2.49*	*2.37*	*2.29*	*2.20*	*2.11*	*2.05*	*1.97*	*1.94*	*1.88*	*1.84*	*1.81*
42	4.07	3.22	2.83	2.59	2.44	2.32	2.24	2.17	2.11	2.06	2.02	1.99	1.94	1.89	1.82	1.78	1.73	1.68	1.64	1.60	1.57	1.54	1.51	1.49
	7.27	*5.15*	*4.29*	*3.80*	*3.49*	*3.26*	*3.10*	*2.96*	*2.86*	*2.77*	*2.70*	*2.64*	*2.54*	*2.46*	*2.35*	*2.26*	*2.17*	*2.08*	*2.02*	*1.94*	*1.91*	*1.85*	*1.80*	*1.78*
44	4.06	3.21	2.82	2.58	2.43	2.31	2.23	2.16	2.10	2.05	2.01	1.98	1.92	1.88	1.81	1.76	1.72	1.66	1.63	1.58	1.56	1.52	1.50	1.48
	7.24	*5.12*	*4.26*	*3.78*	*3.46*	*3.24*	*3.07*	*2.94*	*2.84*	*2.75*	*2.68*	*2.62*	*2.52*	*2.44*	*2.32*	*2.24*	*2.15*	*2.06*	*2.00*	*1.92*	*1.88*	*1.82*	*1.78*	*1.76*
46	4.05	3.20	2.81	2.57	2.42	2.30	2.22	2.14	2.09	2.04	2.00	1.97	1.91	1.87	1.80	1.75	1.71	1.65	1.62	1.57	1.54	1.51	1.48	1.46
	7.21	*5.10*	*4.24*	*3.76*	*3.44*	*3.22*	*3.05*	*2.92*	*2.82*	*2.73*	*2.66*	*2.60*	*2.50*	*2.42*	*2.30*	*2.22*	*2.13*	*2.04*	*1.98*	*1.90*	*1.86*	*1.80*	*1.76*	*1.72*
48	4.04	3.19	2.80	2.56	2.41	2.30	2.21	2.14	2.08	2.03	1.99	1.96	1.90	1.86	1.79	1.74	1.70	1.64	1.61	1.56	1.53	1.50	1.47	1.45
	7.19	*5.08*	*4.22*	*3.74*	*3.42*	*3.20*	*3.04*	*2.90*	*2.80*	*2.71*	*2.64*	*2.58*	*2.48*	*2.40*	*2.28*	*2.20*	*2.11*	*2.02*	*1.96*	*1.88*	*1.84*	*1.78*	*1.73*	*1.70*

n_2	n_1 degrees of freedom (for greater mean square)																							
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
50	4.03 *7.17*	3.18 *5.06*	2.79 *4.20*	2.56 *3.72*	2.40 *3.41*	2.29 *3.18*	2.20 *3.02*	2.13 *2.88*	2.07 *2.78*	2.02 *2.70*	1.98 *2.62*	1.95 *2.56*	1.90 *2.46*	1.85 *2.39*	1.78 *2.26*	1.74 *2.18*	1.69 *2.10*	1.63 *2.00*	1.60 *1.94*	1.55 *1.86*	1.52 *1.82*	1.48 *1.76*	1.46 *1.71*	1.44 *1.68*
55	4.02 *7.12*	3.17 *5.01*	2.78 *4.16*	2.54 *3.68*	2.38 *3.37*	2.27 *3.15*	2.18 *2.98*	2.11 *2.85*	2.05 *2.75*	2.00 *2.66*	1.97 *2.59*	1.93 *2.53*	1.88 *2.43*	1.83 *2.35*	1.76 *2.23*	1.72 *2.15*	1.67 *2.06*	1.61 *1.96*	1.58 *1.90*	1.52 *1.82*	1.50 *1.78*	1.46 *1.71*	1.43 *1.66*	1.41 *1.64*
60	4.00 *7.08*	3.15 *4.98*	2.76 *4.13*	2.52 *3.65*	2.37 *3.34*	2.25 *3.12*	2.17 *2.95*	2.10 *2.82*	2.04 *2.72*	1.99 *2.63*	1.95 *2.56*	1.92 *2.50*	1.86 *2.40*	1.81 *2.32*	1.75 *2.20*	1.70 *2.12*	1.65 *2.03*	1.59 *1.93*	1.56 *1.87*	1.50 *1.79*	1.48 *1.74*	1.44 *1.68*	1.41 *1.63*	1.39 *1.60*
65	3.99 *7.04*	3.14 *4.95*	2.75 *4.10*	2.51 *3.62*	2.36 *3.31*	2.24 *3.09*	2.15 *2.93*	2.08 *2.79*	2.02 *2.70*	1.98 *2.61*	1.94 *2.54*	1.90 *2.47*	1.85 *2.37*	1.80 *2.30*	1.73 *2.18*	1.68 *2.09*	1.63 *2.00*	1.57 *1.90*	1.54 *1.84*	1.49 *1.76*	1.46 *1.71*	1.42 *1.64*	1.39 *1.60*	1.37 *1.56*
70	3.98 *7.01*	3.13 *4.92*	2.74 *4.08*	2.50 *3.60*	2.35 *3.29*	2.23 *3.07*	2.14 *2.91*	2.07 *2.77*	2.01 *2.67*	1.97 *2.59*	1.93 *2.51*	1.89 *2.45*	1.84 *2.35*	1.79 *2.28*	1.72 *2.15*	1.67 *2.07*	1.62 *1.98*	1.56 *1.88*	1.53 *1.82*	1.47 *1.74*	1.45 *1.69*	1.40 *1.62*	1.37 *1.56*	1.35 *1.53*
80	3.96 *6.96*	3.11 *4.88*	2.72 *4.04*	2.48 *3.56*	2.33 *3.25*	2.21 *3.04*	2.12 *2.87*	2.05 *2.74*	1.99 *2.64*	1.95 *2.55*	1.91 *2.48*	1.88 *2.41*	1.82 *2.32*	1.77 *2.24*	1.70 *2.11*	1.65 *2.03*	1.60 *1.94*	1.54 *1.84*	1.51 *1.78*	1.45 *1.70*	1.42 *1.65*	1.38 *1.57*	1.35 *1.52*	1.32 *1.49*
100	3.94 *6.90*	3.09 *4.82*	2.70 *3.98*	2.46 *3.51*	2.30 *3.20*	2.19 *2.99*	2.10 *2.82*	2.03 *2.69*	1.97 *2.59*	1.92 *2.51*	1.88 *2.43*	1.85 *2.36*	1.79 *2.26*	1.75 *2.19*	1.68 *2.06*	1.63 *1.98*	1.57 *1.89*	1.51 *1.79*	1.48 *1.73*	1.42 *1.64*	1.39 *1.59*	1.34 *1.51*	1.30 *1.46*	1.28 *1.43*
125	3.92 *6.84*	3.07 *4.78*	2.68 *3.94*	2.44 *3.47*	2.29 *3.17*	2.17 *2.95*	2.08 *2.79*	2.01 *2.65*	1.95 *2.56*	1.90 *2.47*	1.86 *2.40*	1.83 *2.40*	1.77 *2.33*	1.72 *2.15*	1.65 *2.03*	1.60 *1.94*	1.55 *1.85*	1.49 *1.75*	1.45 *1.68*	1.39 *1.59*	1.36 *1.54*	1.31 *1.46*	1.27 *1.40*	1.25 *1.37*
150	3.91 *6.81*	3.06 *4.75*	2.67 *3.91*	2.43 *3.44*	2.27 *3.14*	2.16 *2.92*	2.07 *2.76*	2.00 *2.62*	1.94 *2.53*	1.89 *2.44*	1.85 *2.37*	1.82 *2.30*	1.76 *2.20*	1.71 *2.12*	1.64 *2.00*	1.59 *1.91*	1.54 *1.83*	1.47 *1.72*	1.44 *1.66*	1.37 *1.56*	1.34 *1.51*	1.29 *1.43*	1.25 *1.37*	1.22 *1.33*
200	3.89 *6.76*	3.04 *4.71*	2.65 *3.88*	2.41 *3.41*	2.26 *3.11*	2.14 *2.90*	2.05 *2.73*	1.98 *2.60*	1.92 *2.50*	1.87 *2.41*	1.83 *2.34*	1.80 *2.28*	1.74 *2.17*	1.69 *2.09*	1.62 *1.97*	1.57 *1.88*	1.52 *1.79*	1.45 *1.69*	1.42 *1.62*	1.35 *1.53*	1.32 *1.48*	1.26 *1.39*	1.22 *1.33*	1.19 *1.28*
400	3.86 *6.70*	3.02 *4.66*	2.62 *3.83*	2.39 *3.36*	2.23 *3.06*	2.12 *2.85*	2.03 *2.69*	1.96 *2.55*	1.90 *2.46*	1.85 *2.37*	1.81 *2.29*	1.78 *2.23*	1.72 *2.12*	1.67 *2.04*	1.60 *1.92*	1.54 *1.84*	1.49 *1.74*	1.42 *1.64*	1.38 *1.57*	1.32 *1.47*	1.28 *1.42*	1.22 *1.32*	1.16 *1.24*	1.13 *1.19*
1000	3.85 *6.66*	3.00 *4.62*	2.61 *3.80*	2.38 *3.34*	2.22 *3.04*	2.10 *2.82*	2.02 *2.66*	1.95 *2.53*	1.89 *2.43*	1.84 *2.34*	1.80 *2.26*	1.76 *2.20*	1.70 *2.09*	1.65 *2.01*	1.58 *1.89*	1.53 *1.81*	1.47 *1.71*	1.41 *1.61*	1.36 *1.54*	1.30 *1.44*	1.26 *1.38*	1.19 *1.28*	1.13 *1.19*	1.08 *1.11*
∞	3.84 *6.64*	2.99 *4.60*	2.60 *3.78*	2.37 *3.32*	2.21 *3.02*	2.09 *2.80*	2.01 *2.64*	1.94 *2.51*	1.88 *2.41*	1.83 *2.32*	1.79 *2.24*	1.75 *2.18*	1.69 *2.07*	1.64 *1.99*	1.57 *1.87*	1.52 *1.79*	1.46 *1.69*	1.40 *1.59*	1.35 *1.52*	1.28 *1.41*	1.24 *1.36*	1.17 *1.25*	1.11 *1.15*	1.00 *1.00*

APPENDIX F

Time Series Analysis Programs

F.1 Autoregressive Spectral Identification Program (ARSPID)

ARSPID is a univariate time series analysis program. Mean monthly maximum temperatures for Highland Home, Alabama from 1893 to 1950 were used as input in the ARSPID program. The data were reduced within the program to annual mean temperatures; all indicators, including the correlogram discussed below, indicate the data are stochastic.

The correlogram, shown in Figure F.1.1, is a graph of r_k versus lag k, where r_k is the autocorrelation coefficient at lag k and r_k is given by the formula below.

$$r_k = \frac{\sum_{t=1}^{N-k} (x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^{N} (x_t - \bar{x})^2}$$

F.2 Multiple Spectral Density Estimation (MULTSP) Program

MULTSP is a bivariate analysis program which can be used to test multiple series for similarity. The program is very versatile in that it can shift series and determine if series are similar when time lags are introduced, among many other features. The program was applied to 'moderate' and 'extreme' series as discussed in the text in Section 4d. The squared coherency, shown in Figure F.2.1, and all other indicators revealed no significant difference between the moderate and extreme series. The squared

coherency measures strength of association between two series as does the correlation coefficient of simple statistics. For more information on time series analysis programs, see Newton (1983).

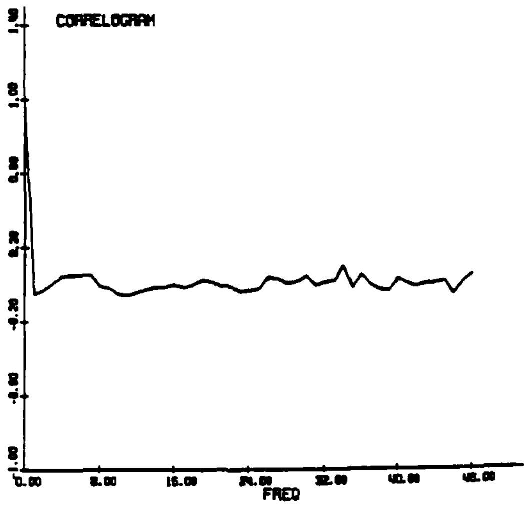


Figure F.1.1 Correlogram of mean annual maximum temperatures at Highland Home, AL 1893 - 1950.

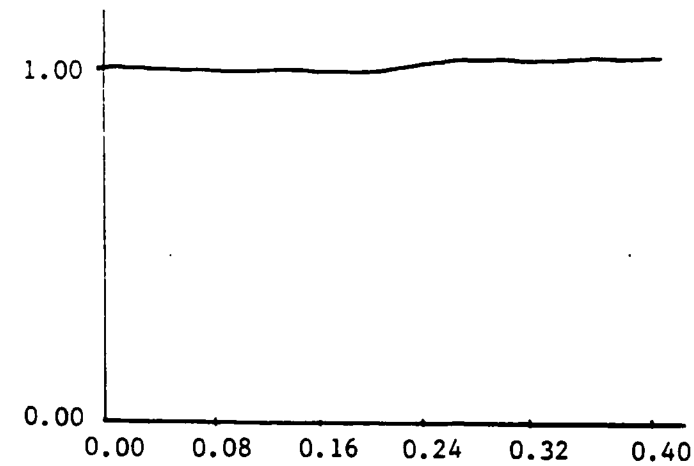


Figure F.2.1a Squared Coherency of 'Moderate' Series of Mean Maximum Monthly Temperatures for Highland Home, AL for the period 1900 - 1970.

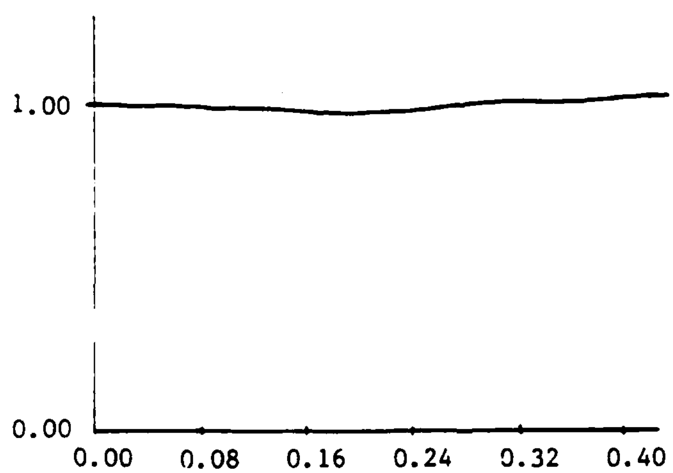


Figure F.2.1b Squared Coherency of 'Extreme' Series of Mean Maximum Monthly Temperatures for Highland Home, AL for the period 1900 - 1970.

APPENDIX G

Annual Mean Values of Twelve Overall Mean Series, including Annual Means, Standard Errors of the Means, Deviation from the 70-year mean (temperature) or Percentage of the 70-year mean (precipitation), and the Standard Errors of the Means for the Deviations and Percentages.

Mean
Winter
Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Dev	Std Error of Deviation
901	30.36	0.88	-0.28	0.17
902	28.48	0.83	-2.16	0.24
903	28.54	1.01	-2.10	0.17
904	26.91	1.08	-3.73	0.29
905	25.60	0.96	-5.05	0.23
906	31.83	0.84	1.19	0.21
907	31.84	1.10	1.20	0.26
908	32.54	0.81	1.90	0.20
909	32.53	1.02	1.89	0.17
910	26.57	0.98	-4.07	0.17
911	31.47	1.02	0.83	0.17
912	27.04	0.99	-3.60	0.18
913	30.75	0.99	0.11	0.22
914	31.61	0.88	0.96	0.14
915	29.10	0.83	-1.54	0.16
916	29.96	1.07	-0.68	0.19
917	27.66	1.18	-2.98	0.29
918	25.79	1.04	-4.85	0.30
919	33.31	0.84	2.67	0.22
920	28.75	1.02	-1.89	0.19
921	34.55	0.83	3.91	0.17
922	30.74	1.05	0.09	0.20
923	31.64	1.07	0.99	0.20
924	31.79	0.88	1.14	0.12
925	30.01	1.05	-0.63	0.18
926	32.34	0.84	1.70	0.19
927	32.56	1.02	1.91	0.14
928	30.68	0.94	0.04	0.13
929	27.64	1.05	-3.00	0.21
930	31.65	0.95	1.01	0.13
931	34.31	0.71	3.67	0.38
932	35.20	1.07	4.56	0.35
933	31.84	1.00	1.20	0.29
934	33.66	0.96	3.02	0.26
935	32.19	0.93	1.55	0.16
936	24.51	1.13	-6.13	0.31
937	30.02	1.15	-0.62	0.34
938	32.32	0.98	1.68	0.13
939	32.34	0.98	1.69	0.13
940	29.47	0.80	-1.17	0.28
941	32.37	0.88	1.72	0.12
942	31.88	0.78	1.23	0.22
943	31.21	1.03	0.56	0.17
944	32.83	0.84	2.19	0.22
945	30.65	0.89	0.01	0.18
946	30.80	0.93	0.16	0.14
947	32.11	0.87	1.46	0.12
948	29.39	0.92	-1.25	0.18
949	30.25	1.16	-0.39	0.46
950	32.19	1.15	1.55	0.31
951	30.70	0.93	0.06	0.17
952	32.43	1.05	1.79	0.22
953	34.10	0.85	3.46	0.14
954	34.42	0.84	3.78	0.15
955	30.57	0.90	-0.07	0.16
956	29.63	1.02	-1.02	0.19
957	32.74	1.04	2.09	0.18
958	31.62	0.73	0.98	0.29
959	28.88	0.99	-1.76	0.20
960	31.14	0.81	0.50	0.20
961	30.99	0.80	0.35	0.23
962	29.11	1.02	-1.53	0.16
963	27.71	0.87	-2.93	0.25
964	29.01	0.75	-1.63	0.27
965	29.9[illegible]	1.03	-0.68	0.18
966	30.01	0.87	-0.63	0.16
967	30.86	0.88	0.22	0.15
968	29.55	0.84	-1.09	0.16
969	28.71	0.82	-1.94	0.17
970	29.05	0.86	-1.60	0.27

Mean
Minimum
Annual
Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Dev	Std Error of Deviation
901	39.94	0.61	-0.40	0.12
902	40.17	0.68	-0.17	0.10
903	39.15	0.69	-1.19	0.12
904	38.54	0.70	-1.80	0.13
905	39.44	0.70	-0.90	0.11
906	40.48	0.67	0.14	0.11
907	39.79	0.73	-0.55	0.14
908	40.76	0.68	0.42	0.10
909	40.01	0.68	-0.33	0.10
910	39.99	0.63	-0.35	0.11
911	40.85	0.72	0.51	0.13
912	38.84	0.69	-1.50	0.11
913	40.72	0.68	0.38	0.11
914	40.40	0.65	0.06	0.08
915	40.45	0.65	0.11	0.09
916	39.05	0.72	-1.29	0.11
917	37.55	0.70	-2.79	0.13
918	40.32	0.66	-0.01	0.08
919	40.76	0.68	0.42	0.09
920	40.17	0.64	-0.17	0.09
921	42.87	0.65	2.53	0.10
922	41.26	0.71	0.82	0.11
923	40.68	0.69	0.34	0.09
924	38.55	0.68	-1.79	0.09
925	40.67	0.67	0.33	0.10
926	40.26	0.65	-0.08	0.10
927	40.77	0.70	0.43	0.09
928	40.47	0.63	0.13	0.07
929	39.37	0.71	-0.97	0.10
930	40.65	0.63	0.31	0.09
931	42.80	0.59	2.47	0.15
932	40.56	0.70	0.22	0.10
933	41.66	0.70	1.32	0.10
934	41.89	0.63	1.55	0.13
935	41.11	0.68	0.77	0.08
936	40.03	0.70	-0.31	0.10
937	40.17	0.68	-0.17	0.10
938	42.18	0.64	1.84	0.07
939	41.38	0.65	1.04	0.08
940	40.04	0.58	-0.30	0.14
941	42.14	0.60	1.80	0.12
942	40.72	0.62	0.38	0.09
943	39.84	0.66	-0.50	0.10
944	40.82	0.65	0.49	0.11
945	40.38	0.69	0.04	0.09
946	41.76	0.67	1.42	0.10
947	40.66	0.63	0.32	0.08
948	40.17	0.66	-0.16	0.10
949	40.79	0.69	0.45	0.14
950	39.05	0.72	-1.29	0.13
951	39.22	0.70	-1.12	0.11
952	40.54	0.63	0.20	0.09
953	41.59	0.60	1.25	0.10
954	41.55	0.61	1.22	0.11
955	40.15	0.66	-0.19	0.08
956	40.33	0.66	-0.00	0.09
957	41.10	0.66	0.76	0.08
958	39.97	0.59	-0.37	0.12
959	40.54	0.64	0.20	0.08
960	39.50	0.61	-0.84	0.09
961	40.09	0.60	-0.25	0.10
962	40.07	0.63	-0.27	0.09
963	39.98	0.58	-0.36	0.17
964	40.03	0.65	-0.31	0.10
965	40.13	0.66	-0.20	0.09
966	39.22	0.62	-1.12	0.10
967	39.53	0.63	-0.81	0.11
968	39.60	0.58	-0.74	0.12
969	39.71	0.60	-0.63	0.12
970	39.79	0.61	-0.55	0.10

Mean
Winter
Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Dev	Std Error of Deviation
901	30.36	0.88	-0.28	0.17
902	28.48	0.83	-2.16	0.24
903	28.54	1.01	-2.10	0.17
904	26.91	1.08	-3.73	0.28
905	25.60	0.96	-5.05	0.23
906	31.83	0.84	1.19	0.21
907	31.84	1.10	1.20	0.26
908	32.54	0.81	1.90	0.20
909	32.53	1.02	1.89	0.17
910	26.57	0.98	-4.07	0.17
911	31.47	1.02	0.83	0.17
912	27.04	0.99	-3.60	0.18
913	30.75	0.99	0.11	0.22
914	31.61	0.88	0.96	0.14
915	29.10	0.93	-1.54	0.16
916	29.96	1.07	-0.68	0.19
917	27.66	1.18	-2.98	0.29
918	25.79	1.04	-4.85	0.30
919	33.31	0.84	2.67	0.22
920	28.75	1.02	-1.89	0.19
921	34.55	0.83	3.91	0.17
922	30.74	1.05	0.09	0.20
923	31.64	1.07	0.99	0.20
924	31.79	0.88	1.14	0.12
925	30.01	1.05	-0.63	0.18
926	32.34	0.84	1.70	0.19
927	32.56	1.02	1.91	0.14
928	30.68	0.94	0.04	0.13
929	27.64	1.05	-3.00	0.21
930	31.65	0.95	1.01	0.13
931	34.31	0.71	3.67	0.38
932	35.20	1.07	4.56	0.35
933	31.84	1.00	1.20	0.29
934	33.66	0.96	3.02	0.26
935	32.19	0.93	1.55	0.16
936	24.51	1.13	-6.13	0.31
937	30.02	1.15	-0.62	0.34
938	32.32	0.98	1.68	0.13
939	32.34	0.98	1.69	0.13
940	29.47	0.80	-1..17	0.28
941	32.37	0.88	1.72	0.12
942	31.88	0.78	1.23	0.22
943	31.21	1.03	0.56	0.17
944	32.83	0.84	2.19	0.22
945	30.65	0.89	0.01	0.18
946	30.80	0.93	0.16	0.14
947	32.11	0.87	1.46	0.12
948	29.39	0.92	-1.25	0.18
949	30.25	1.16	-0.39	0.46
950	32.19	1.15	1.55	0.31
951	30.70	0.93	0.06	0.17
952	32.43	1.05	1.79	0.22
953	34.10	0.85	3.46	0.14
954	34.42	0.84	3.78	0.15
955	30.57	0.90	-0.07	0.16
956	29.63	1.02	-1.02	0.19
957	32.74	1.04	2.09	0.18
958	31.62	0.73	0.98	0.29
959	28.88	0.99	-1.76	0.20
960	31.14	0.81	0.50	0.20
961	30.99	0.80	0.35	0.23
962	29.11	1.02	-1.53	0.16
963	27.71	0.87	-2.93	0.25
964	29.01	0.75	-1.63	0.27
965	29.96	1.03	-0.68	0.18
966	30.01	0.87	-0.63	0.16
967	30.86	0.88	0.22	0.15
968	29.55	0.84	-1.09	0.16
969	28.71	0.92	-1.94	0.17
970	29.05	0.86	-1.60	0.27

Mean Maximum Winter Temperature

Year (1901-1970)	Mean	Std Err of Mean	Mean Dev	Std Error of Deviation
901	40.70	0.91	-0.49	0.22
902	38.76	0.87	-2.43	0.27
903	38.43	0.99	-2.76	0.19
904	38.11	1.13	-3.08	0.31
905	36.15	0.95	-5.03	0.26
906	42.65	0.86	1.46	0.29
907	42.11	1.14	0.92	0.26
908	42.98	0.83	1.79	0.25
909	43.00	1.06	1.82	0.20
910	36.69	1.03	-4.49	0.21
911	42.01	1.05	0.82	0.18
912	37.06	1.04	-4.13	0.25
913	41.83	0.96	0.64	0.24
914	41.68	0.89	0.49	0.18
915	38.52	0.92	-2.66	0.18
916	40.38	1.11	-0.81	0.21
917	39.05	1.20	-2.13	0.31
918	36.91	1.07	-4.28	0.28
919	43.21	0.88	2.02	0.24
920	38.84	1.07	-2.35	0.22
921	44.66	0.88	3.47	0.19
922	41.45	1.04	0.26	0.21
923	42.27	1.09	1.08	0.22
924	42.49	0.88	1.30	0.17
925	40.64	1.07	-0.54	0.23
926	42.47	0.89	1.28	0.21
927	42.77	1.05	1.58	0.17
928	41.54	0.98	0.35	0.17
929	38.31	1.07	-2.88	0.23
930	42.43	1.00	1.24	0.15
931	44.71	0.75	3.53	0.40
932	44.95	1.09	3.76	0.38
[illegible]	42.99	0.98	1.80	0.29
934	44.75	1.00	3.57	0.27
935	42.30	1.00	1.11	0.19
936	34.55	1.17	-6.63	0.33
937	40.15	1.12	-1.04	0.34
938	42.18	1.00	0.99	0.14
939	43.31	1.03	2.12	0.18
940	39.60	0.86	-1.58	0.28
941	42.00	0.82	0.81	0.14
942	42.00	0.82	0.81	0.23
943	42.35	1.08	1.16	0.20
944	43.92	0.82	2.73	0.26
945	40.57	0.94	-0.61	0.19
946	41.80	0.95	0.62	0.22
947	42.94	0.91	1.76	0.13
948	40.04	0.93	-1.15	0.21
949	40.53	1.14	-0.66	0.45
950	43.49	1.16	2.31	0.31
951	41.93	0.99	0.74	0.19
952	42.97	1.10	1.79	0.26
953	44.37	0.91	3.18	0.14
954	45.77	0.90	4.58	0.16
955	41.13	0.94	-0.06	0.15
956	40.10	1.05	-1.09	0.21
957	43.43	1.05	2.24	0.18
958	42.13	0.77	0.94	0.30
959	39.98	1.00	-1.21	0.18
960	40.66	0.85	-0.53	0.20
961	42.40	0.83	1.21	0.25
962	39.64	1.08	-1.55	0.20
963	39.21	0.91	-1.98	0.25
964	40.26	0.77	-0.92	0.27
965	41.12	1.05	-0.06	0.18
966	40.47	0.88	-0.71	0.17
967	42.01	0.91	0.82	0.17
968	40.18	0.85	-1.01	0.17
969	38.29	1.00	-2.90	0.22
970	39.86	0.92	-1.33	0.27

Mean Maximum Annual Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Dev	Std Error of Deviation
901	64.13	0.60	-0.25	0.16
902	63.40	0.63	-0.98	0.12
903	62.69	0.63	-1.69	0.11
904	62.95	0.70	-1.43	0.15
905	62.76	0.64	-1.62	0.13
906	63.74	0.64	-0.64	0.10
907	63.51	0.72	-0.87	0.14
908	64.92	0.64	0.54	0.11
909	63.50	0.72	-0.88	0.14
910	64.91	0.63	0.53	0.14
911	64.95	0.70	0.57	0.13
912	62.28	0.66	-2.10	0.19
913	64.80	0.63	0.42	0.14
914	64.30	0.63	-0.08	0.10
915	63.16	0.65	-1.22	0.12
916	63.57	0.73	-0.81	0.14
917	62.10	0.73	-2.28	0.14
918	64.63	0.65	0.25	0.11
919	63.81	0.67	-0.57	0.14
920	63.17	0.63	-1.21	0.09
921	66.99	0.65	2.61	0.11
922	65.11	0.66	0.73	0.13
923	64.13	0.63	-0.25	0.10
924	62.63	0.68	-1.75	0.12
925	64.99	0.68	0.61	0.11
926	64.10	0.66	-0.28	0.14
927	64.32	0.73	-0.06	0.14
928	64.49	0.63	0.10	0.11
929	63.08	0.69	-1.30	0.13
930	65.18	0.61	0.80	0.12
931	67.10	0.57	2.72	0.15
932	64.43	0.66	0.04	0.12
933	66.52	0.68	2.14	0.13
934	67.18	0.64	2.80	0.17
935	64.08	0.68	-0.30	0.12
936	65.16	0.69	0.78	0.11
937	63.77	0.66	-0.61	0.09
938	66.39	0.66	2.01	0.11
939	66.95	0.64	2.57	0.12
940	63.72	0.63	-0.66	0.13
941	65.30	0.61	0.82	0.11
942	64.28	0.63	-0.10	0.10
943	64.96	0.67	0.58	0.11
944	64.53	0.63	0.15	0.11
945	64.01	0.67	-0.37	0.11
946	66.11	0.62	1.73	0.10
947	63.98	0.62	-0.40	0.08
948	64.40	0.63	0.02	0.10
949	64.84	0.61	0.45	0.14
950	63.23	0.71	-1.15	0.14
951	63.01	0.74	-1.37	0.17
952	65.47	0.63	1.08	0.09
953	66.56	0.62	2.18	0.10
954	66.40	0.69	2.02	0.12
955	64.90	0.64	0.52	0.10
956	65.50	0.67	1.12	0.11
957	64.08	0.62	-0.30	0.10
958	63.59	0.56	-0.79	0.16
959	64.45	0.61	0.07	0.10
960	63.30	0.60	-1.09	0.11
961	63.95	0.58	-0.43	0.11
962	63.91	0.65	-0.47	0.09
963	64.93	0.59	0.55	0.14
964	64.89	0.60	0.51	0.13
965	63.94	0.66	-0.44	0.10
966	63.65	0.60	-0.73	0.11
967	63.88	0.63	-0.51	0.11
968	63.63	0.57	-0.75	0.12
969	62.96	0.62	-1.42	0.12
970	63.93	0.62	-0.46	0.10

Mean Maximum Summer Temperature

Year (1901-1970)	Mean	Std Err of Mean	Mean Dev	Std Error of Deviation
901	88.22	0.51	2.55	0.26
902	83.99	0.52	-1.68	0.23
903	82.68	0.47	-2.99	0.20
904	83.01	0.44	-2.66	0.19
905	83.99	0.50	-1.68	0.25
906	84.22	0.43	-1.44	0.17
907	83.93	0.50	-1.74	0.18
908	83.89	0.45	-1.78	0.20
909	85.38	0.46	-0.29	0.16
910	85.21	0.44	-0.46	0.20
911	86.70	0.49	1.03	0.19
912	83.41	0.50	-2.26	0.22
913	87.47	0.53	1.80	0.25
914	86.81	0.52	1.14	0.20
915	81.38	0.52	-4.29	0.27
916	85.20	0.46	-0.47	0.15
917	84.68	0.49	-0.99	0.16
918	86.89	0.54	1.22	0.19
919	86.08	0.40	0.42	0.18
920	83.98	0.41	-1.69	0.14
921	86.91	0.42	1.24	0.15
922	86.11	0.46	0.44	0.14
923	84.79	0.43	-0.88	0.15
924	84.23	0.53	-1.43	0.21
925	86.49	0.51	0.82	0.18
926	85.66	0.47	-0.01	0.16
927	82.92	0.46	-2.75	0.17
928	83.85	0.45	-1.82	0.17
929	85.61	0.42	-0.06	0.15
930	87.74	0.45	2.07	0.15
931	88.01	0.43	2.34	0.17
932	86.63	0.44	0.96	0.13
933	88.37	0.42	2.70	0.18
934	90.02	0.56	4.35	0.27
935	86.35	0.46	0.68	0.17
936	90.96	0.54	5.29	0.28
937	87.58	0.43	1.91	0.13
938	86.94	0.44	1.27	0.15
939	86.91	0.44	1.24	0.14
940	86.27	0.44	0.60	0.19
941	86.18	0.43	0.52	0.15
942	85.01	0.45	-0.66	0.14
943	87.16	0.48	1.49	0.17
944	86.10	0.46	0.43	0.19
945	83.77	0.44	-1.90	0.16
946	85.00	0.46	-0.67	0.17
947	85.47	0.41	-0.20	0.13
948	85.54	0.45	-0.13	0.14
949	86.18	0.35	0.51	0.17
950	83.17	0.43	-2.50	0.19
951	83.78	0.53	-1.89	0.24
952	87.74	0.50	2.07	0.17
953	87.31	0.47	1.64	0.16
954	87.64	0.58	1.97	0.22
955	86.55	0.37	0.88	0.17
956	86.44	0.50	0.78	0.15
957	85.74	0.41	0.07	0.11
958	84.25	0.44	-1.42	0.18
959	86.59	0.37	0.92	0.18
960	85.24	0.41	-0.43	0.15
961	85.33	0.34	-0.34	0.23
962	84.55	0.46	-1.12	0.13
963	85.95	0.44	0.28	0.16
964	85.42	0.44	-0.25	0.13
965	84.07	0.40	-1.60	0.13
966	85.52	0.37	-0.15	0.14
967	83.48	0.37	-2.19	0.19
968	84.99	0.41	-0.68	0.15
969	84.97	0.44	-0.70	0.14
970	86.26	0.37	0.59	0.18

Mean Minimum Summer Temperature

Year (1901-1970)	Mean	Std Err of Mean	Mean Dev	Std Error of Deviation
901	61.54	0.58	1.45	0.19
902	58.98	0.61	-1.10	0.15
903	58.23	0.55	-1.86	0.15
904	58.05	0.54	-2.04	0.15
905	59.97	0.57	-0.12	0.13
906	59.37	0.56	-0.72	0.22
907	58.98	0.59	-1.11	0.13
908	59.09	0.57	-1.00	0.12
909	60.79	0.56	0.70	0.12
910	58.97	0.54	-1.12	0.12
911	60.05	0.57	-0.04	0.12
912	58.94	0.57	-1.15	0.12
913	60.80	0.53	0.71	0.11
914	60.94	0.58	0.85	0.12
915	57.63	0.59	-2.46	0.18
916	60.02	0.57	-0.07	0.13
917	58.33	0.57	-1.76	0.21
918	60.27	0.55	0.18	0.13
919	60.97	0.52	0.88	0.13
920	58.86	0.52	-1.23	0.13
921	61.84	0.54	1.75	0.12
922	60.50	0.51	0.41	0.13
923	60.52	0.55	0.43	0.11
924	58.84	0.60	-1.25	0.14
925	60.11	0.56	0.02	0.11
926	59.54	0.54	-0.55	0.10
927	57.86	0.55	-2.23	0.14
928	59.40	0.58	-0.69	0.13
929	59.21	0.52	-0.88	0.11
930	60.01	0.50	-0.08	0.13
931	61.30	0.49	1.21	0.12
932	61.14	0.57	1.05	0.10
933	61.17	0.51	1.08	0.10
934	62.33	0.63	2.25	0.20
935	61.15	0.54	1.06	0.11
936	62.24	0.54	2.15	0.16
937	61.65	0.52	1.56	0.10
938	61.35	0.52	1.26	0.09
939	60.79	0.56	0.70	0.08
940	60.44	0.51	0.35	0.10
941	60.94	0.53	0.85	0.11
942	60.49	0.55	0.40	0.10
943	61.72	0.59	1.63	0.13
944	60.12	0.59	0.04	0.13
945	59.01	0.56	-1.08	0.12
946	59.57	0.53	-0.52	0.11
947	60.48	0.53	0.40	0.12
948	60.28	0.53	0.19	0.10
949	61 27	0.54	1.19	0.14
950	57.94	0.56	-2.15	0.14
951	59.23	0.58	-0.86	0.12
952	61.31	0.57	1.22	0.10
953	60.91	0.56	0.82	0.11
954	61.22	0.61	1.13	0.16
955	61.02	0.49	0.93	0.15
956	60.20	0.53	0.11	0.11
957	60.56	0.54	0.47	0.11
958	59.61	0.55	-0.48	0.13
959	61.07	0.49	0.98	0.11
960	59.81	0.52	-0.28	0.09
961	59.82	0.44	-0.26	0.15
962	59.42	0.55	-0.67	0.09
963	60.59	0.53	0.50	0.17
964	59.80	0.54	-0.29	0.09
965	59.34	0.53	-0.75	0.11
966	59.76	0.50	-0.33	0.13
967	58.55	0.46	-1.54	0.14
968	59.99	0.52	-0.10	0.09
969	59.78	0.52	-0.31	0.10
970	60.25	0.46	0.16	0.13

Mean Minimum Winter Temperature

Year (1901-1970)	Mean	Std Err of Mean	Mean Dev	Std Error of Deviation
901	20.02	0.89	-0.08	0.17
902	18.20	0.82	-1.90	0.25
903	18.65	1.05	-1.45	0.21
904	15.72	1.08	-4.38	0.30
905	15.04	1.01	-5.06	0.27
906	21.02	0.87	0.92	0.18
907	21.58	1.08	1.48	0.28
908	22.10	0.83	2.01	0.20
909	22.06	1.00	1.96	0.17
910	16.45	0.95	-3.64	0.17
911	20.93	1.02	0.83	0.22
912	17.02	0.96	-3.08	0.16
913	19.68	1.05	-0.42	0.24
914	21.53	0.90	1.43	0.15
915	19.68	0.95	-0.41	0.17
916	19.55	1.05	-0.55	0.20
917	16.26	1.18	-3.83	0.30
918	14.67	1.04	-5.42	0.34
919	23.41	0.82	3.31	0.23
920	18.66	0.99	-1.44	0.21
921	24.45	0.80	4.35	0.19
922	20.02	1.08	-0.08	0.23
923	21.00	1.08	0.90	0.21
924	21.09	0.91	0.99	0.13
925	19.38	1.04	-0.72	0.17
926	22.22	0.82	2.12	0.21
927	22.34	1.00	2.24	0.14
928	19.83	0.92	-0.27	0.13
929	16.97	1.04	-3.13	0.22
930	20.88	0.91	0.78	0.15
931	23.91	0.71	3.81	0.37
932	25.45	1.07	5.35	0.35
933	20.70	1.05	0.60	0.31
934	22.57	0.95	2.47	0.27
935	22.08	0.90	1.98	0.19
936	14.47	1.10	-5.63	0.30
937	19.90	1.19	-0.20	0.37
938	22.46	0.99	2.36	0.16
939	21.36	0.96	1.26	0.12
940	19.34	0.78	-0.76	0.29
941	22.74	0.85	2.64	0.16
942	21.75	0.76	1.66	0.25
943	20.06	0.99	-0.04	0.17
944	21.74	0.88	1.64	0.21
945	20.72	0.87	0.63	0.22
946	19.80	0.94	-0.30	0.14
947	21.27	0.86	1.17	0.15
948	18.75	0.93	-1.35	0.20
949	19.98	1.19	-0.12	0.49
950	20.89	1.18	0.80	0.34
951	19.47	0.91	-0.63	0.20
952	21.88	1.03	1.78	0.21
953	23.84	0.81	3.74	0.18
954	23.08	0.81	2.98	0.18
955	20.01	0.88	-0.08	0.19
956	19.15	1.01	-0.95	0.20
957	22.04	1.06	1.95	0.21
958	21.12	0.72	1.02	0.29
959	17.78	1.00	-2.32	0.24
960	21.62	0.80	1.52	0.24
961	19.59	0.81	-0.51	0.24
962	18.58	0.99	-1.52	0.14
963	16.22	0.85	-3.88	0.26
964	17.75	0.76	-2.35	0.28
965	18.79	1.03	-1.31	0.20
966	19.55	0.88	-0.55	0.17
967	19.72	0.89	-0.38	0.17
968	18.91	0.85	-1.18	0.19
969	19.12	0.87	-0.97	0.19
970	18.24	0.83	-1.86	0.29

Mean Summer Temperature

Year (1901-1970)	Mean	Std Err of Mean	Mean Dev	Std Error of Deviation
901	74.88	0.49	2.01	0.17
902	71.49	0.52	-1.38	0.15
903	70.45	0.46	-2.41	0.14
904	70.53	0.45	-2.34	0.14
905	71.98	0.48	-0.89	0.14
906	71.80	0.45	-1.07	0.16
907	71.46	0.51	-1.41	0.12
908	71.49	0.47	-1.38	0.13
909	73.09	0.47	0.22	0.10
910	72.09	0.43	-0.77	0.12
911	73.37	0.49	0.51	0.12
912	71.18	0.50	-1.69	0.13
913	74.14	0.50	1.27	0.15
914	73.87	0.52	1.01	0.14
915	69.51	0.52	-3.36	0.21
916	72.61	0.48	-0.25	0.10
917	71.51	0.48	-1.36	0.14
918	73.58	0.51	0.72	0.13
919	73.53	0.41	0.66	0.13
920	71.42	0.42	-1.45	0.09
921	74.37	0.44	1.51	0.11
922	73.31	0.44	0.44	0.09
923	72.66	0.46	-0.21	0.10
924	71.54	0.52	-1.33	0.15
925	73.30	0.51	0.43	0.11
926	72.60	0.46	-0.27	0.11
927	70.39	0.48	-2.47	0.13
928	71.62	0.47	-1.24	0.12
929	72.41	0.44	-0.46	0.10
930	73.87	0.44	1.01	0.09
931	74.65	0.42	1.79	0.13
932	73.88	0.47	1.02	0.09
933	74.77	0.42	1.90	0.12
934	76.17	0.55	3.31	0.20
935	73.75	0.45	0.89	0.10
936	76.60	0.51	3.74	0.20
937	74.61	0.44	1.75	0.10
938	74.15	0.44	1.28	0.10
939	73.85	0.45	0.99	0.08
940	73.35	0.42	0.49	0.13
941	73.56	0.45	0.70	0.10
942	72.75	0.46	-0.11	0.09
943	74.44	0.51	1.57	0.13
944	73.11	0.49	0.24	0.13
945	71.39	0.47	-1.47	0.12
946	72.28	0.44	-0.58	0.11
947	72.98	0.44	0.11	0.10
948	72.91	0.45	0.04	0.09
949	73.73	0.40	0.86	0.13
950	70.55	0.45	-2.31	0.14
951	71.51	0.52	-1.36	0.16
952	74.52	0.50	1.66	0.11
953	74.11	0.48	1.24	0.11
954	74.43	0.56	1.56	0.16
955	73.78	0.40	0.92	0.14
956	73.32	0.48	0.46	0.10
957	73.15	0.44	0.28	0.08
958	71.93	0.46	-0.94	0.13
959	73.83	0.38	0.96	0.12
960	72.52	0.42	-0.34	0.10
961	72.58	0.34	-0.29	0.17
962	71.99	0.47	-0.88	0.07
963	73.27	0.46	0.40	0.15
964	72.61	0.46	-0.26	0.09
965	71.70	0.45	-1.16	0.08
966	72.64	0.40	-0.23	0.10
967	71.01	0.38	-1.85	0.15
968	72.49	0.44	-0.38	0.09
969	72.38	0.45	-0.49	0.09
970	73.26	0.38	0.39	0.14

Mean Minimum Annual Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Deviation	Std Error of Deviation
901	39.94	0.61	-0.40	0.12
902	40.17	0.68	-0.17	0.10
903	39.15	0.69	-1.19	0.12
904	38.54	0.70	-1.80	0.13
905	39.44	0.70	-0.90	0.11
906	40.48	0.67	0.14	0.11
907	39.79	0.73	-0.55	0.14
908	40.76	0.68	0.42	0.10
909	40.01	0.68	-0.33	0.10
910	39.99	0.63	-0.35	0.11
911	40.85	0.72	0.51	0.13
912	38.84	0.69	-1.50	0.11
913	40.72	0.68	0.38	0.11
914	40.40	0.65	0.06	0.08
915	40.45	0.65	0.11	0.09
916	39.05	0.72	-1.29	0.11
917	37.55	0.70	-2.79	0.13
918	40.32	0.66	-0.01	0.08
919	40.76	0.68	0.42	0.09
920	40.17	0.64	-0.17	0.09
921	42.87	0.65	2.53	0.10
922	41.26	0.71	0.92	0.11
923	40.68	0.69	0.34	0.09
924	38.55	0.68	-1.79	0.09
925	40.67	0.67	0.33	0.10
926	40.26	0.65	-0.08	0.10
927	40.77	0.70	0.43	0.09
928	40.47	0.63	0.13	0.07
929	39.37	0.71	-0.97	0.10
930	40.65	0.63	0.31	0.09
931	42.80	0.59	2.47	0.15
932	40.56	0.70	0.22	0.10
933	41.66	0.70	1.32	0.10
934	41.89	0.63	1.55	0.13
935	41.11	0.68	0.77	0.08
936	40.03	0.70	-0.31	0.10
937	40.17	0.68	-0.17	0.10
938	42.18	0.64	1.84	0.07
939	41.38	0.65	1.04	0.08
940	40.04	0.58	-0.30	0.14
941	42.14	0.60	1.80	0.12
942	40.72	0.62	0.38	0.09
943	39.84	0.66	-0.50	0.10
944	40.82	0.65	0.48	0.11
945	40.38	0.69	0.04	0.09
946	41.76	0.67	1.42	0.10
947	40.66	0.63	0.32	0.08
948	40.17	0.66	-0.16	0.10
949	40.79	0.69	0.45	0.14
950	39.05	0.72	-1.29	0.13
951	39.22	0.70	-1.12	0.11
952	40.54	0.63	0.20	0.09
953	41.59	0.60	1.25	0.10
954	41.55	0.61	1.22	0.11
955	40.15	0.66	-0.19	0.08
956	40.33	0.66	-0.00	0.09
957	41.10	0.66	0.76	0.08
958	39.97	0.59	-0.37	0.12
959	40.54	0.64	0.20	0.08
960	39.50	0.61	-0.84	0.09
961	40.09	0.60	-0.25	0.10
962	40.07	0.63	-0.27	0.09
963	39.98	0.58	-0.36	0.17
964	40.03	0.65	-0.31	0.10
965	40.13	0.66	-0.20	0.09
966	39.22	0.62	-1.12	0.10
967	39.53	0.63	-0.81	0.11
968	39.60	0.58	-0.74	0.12
969	39.71	0.60	-0.63	0.12
970	39.79	0.61	-0.55	0.10

Mean
Winter
Precipitation

Year (1901-1970)	Mean	Std Error of Mean	Mean Percent.	Std Error of Percentage
901	4.88	0.39	0.75	0.03
902	6.23	0.46	0.95	0.03
903	8.22	0.50	1.36	0.04
904	5.18	0.35	0.78	0.03
905	5.90	0.38	0.99	0.03
906	6.13	0.43	0.92	0.03
907	6.80	0.43	1.16	0.04
908	7.01	0.45	1.10	0.03
909	6.67	0.49	1.08	0.04
910	6.69	0.38	1.17	0.03
911	5.60	0.39	1.01	0.04
912	6.68	0.47	1.06	0.04
913	6.84	0.53	0.96	0.03
914	6.12	0.39	1.17	0.06
915	7.88	0.46	1.41	0.05
916	7.43	0.51	1.21	0.04
917	5.75	0.41	0.93	0.04
918	4.93	0.33	0.86	0.03
919	6.81	0.38	1.27	0.05
920	5.07	0.40	0.74	0.03
921	5.71	0.41	0.88	0.03
922	5.97	0.39	1.02	0.04
923	6.57	0.52	0.89	0.04
924	6.60	0.46	0.98	0.03
925	6.68	0.46	1.11	0.03
926	5.72	0.39	0.92	0.03
927	6.28	0.44	1.01	0.03
928	5.71	0.35	0.92	0.02
929	6.21	0.38	1.00	0.03
930	6.27	0.45	0.97	0.03
931	4.16	0.29	0.64	0.03
932	8.19	0.60	1.30	0.04
933	6.48	0.46	0.93	0.03
934	5.36	0.35	0.93	0.04
935	5.41	0.36	0.84	0.02
936	6.19	0.47	1.03	0.04
937	8.97	0.61	1.38	0.04
938	5.86	0.43	0.97	0.04
939	7.03	0.45	1.14	0.03
940	5.58	0.40	0.91	0.02
941	5.70	0.40	1.02	0.03
942	5.99	0.44	0.97	0.03
943	5.51	0.37	0.90	0.03
944	5.72	0.39	0.98	0.04
945	6.42	0.45	1.00	0.03
946	6.90	0.49	1.03	0.03
947	4.89	0.34	0.75	0.02
948	6.33	0.41	1.04	0.03
949	8.30	0.49	1.37	0.04
950	8.32	0.67	1.23	0.05
951	6.43	0.45	1.00	0.03
952	7.07	0.51	1.15	0.04
953	6.39	0.44	1.00	0.03
954	5.93	0.41	0.93	0.03
955	6.12	0.38	0.98	0.02
956	5.74	0.55	0.85	0.03
957	5.77	0.48	0.80	0.03
958	6.46	0.45	1.02	0.03
959	5.31	0.38	0.81	0.02
960	7.01	0.39	1.24	0.04
961	5.37	0.40	0.78	0.03
962	7.63	0.56	1.20	0.03
963	4.16	0.32	0.65	0.02
964	5.04	0.43	0.70	0.03
965	7.22	0.51	1.10	0.03
966	6.22	0.41	1.00	0.02
967	5.40	0.37	0.86	0.03
968	5.70	0.41	0.85	0.03
969	7.28	0.49	1.33	0.05
970	5.75	0.49	0.82	0.03

Mean Summer Precipitation

Year (1901-1970)	Mean	Std Error of Mean	Mean Percent.	Std Error of Percentage
901	9.43	0.43	0.89	0.03
902	12.44	0.56	1.15	0.04
903	11.58	0.46	1.08	0.03
904	10.92	0.44	1.02	0.03
905	11.98	0.47	1.14	0.04
906	11.50	0.48	1.13	0.04
907	10.90	0.43	1.13	0.05
908	10.92	0.43	1.07	0.03
909	10.96	0.45	1.06	0.03
910	8.17	0.49	0.82	0.03
911	9.74	0.44	0.91	0.03
912	10.41	0.39	1.04	0.03
913	7.71	0.32	0.82	0.03
914	10.12	0.37	1.03	0.04
915	13.72	0.52	1.27	0.04
916	10.96	0.50	1.04	0.03
917	9.20	0.41	0.84	0.03
918	8.31	0.32	0.81	0.02
919	10.96	0.49	1.00	0.04
920	10.52	0.41	1.06	0.04
921	10.06	0.39	0.96	0.03
922	9.46	0.45	0.88	0.03
923	11.03	0.42	1.09	0.03
924	10.57	0.46	0.97	0.03
925	9.81	0.36	0.98	0.03
926	10.34	0.44	0.95	0.03
927	10.37	0.45	0.99	0.03
928	13.66	0.57	1.25	0.03
929	8.78	0.40	0.86	0.08
930	7.73	0.34	0.77	0.03
931	8.97	0.37	0.86	0.03
932	10.67	0.41	1.03	0.03
933	8.16	0.38	0.76	0.03
934	8.00	0.39	0.76	0.03
935	10.87	0.47	0.99	0.03
936	6.89	0.41	0.78	0.06
937	10.10	0.41	0.99	0.03
938	10.03	0.44	0.92	0.03
939	10.36	0.47	0.96	0.03
940	10.45	0.52	0.94	0.04
941	10.86	0.44	1.08	0.03
942	11.69	0.46	1.09	0.03
943	10.36	0.41	1.03	0.03
944	10.63	0.43	1.06	0.03
945	11.35	0.48	1.12	0.03
946	10.18	0.46	0.97	0.03
947	10.78	0.40	1.11	0.03
948	10.78	0.41	1.07	0.03
949	11.37	0.49	1.04	0.03
950	11.46	0.46	1.09	0.03
951	12.20	0.50	1.16	0.03
952	9.44	0.41	0.94	0.03
953	9.03	0.44	0.92	0.04
954	8.99	0.39	0.91	0.03
955	9.51	0.40	0.93	0.03
956	9.38	0.39	0.88	0.03
957	10.06	0.38	0.98	0.03
958	12.50	0.51	1.17	0.04
959	10.02	0.41	0.95	0.03
960	10.59	0.45	0.99	0.03
961	10.60	0.44	1.01	0.03
962	10.67	0.40	1.02	0.03
963	10.05	0.37	0.99	0.03
964	10.38	0.47	1.07	0.05
965	10.75	0.43	1.13	0.05
966	9.84	0.39	0.95	0.03
967	11.51	0.49	1.16	0.05
968	10.06	0.34	1.05	0.03
969	11.24	0.44	1.09	0.03
970	9.18	0.39	0.91	0.03

Annual Total Precipitation

Year (1901-1970)	Mean	Std Error of Mean	Mean Percentage	Std Error of Percentage
901	30.33	1.10	0.93	0.02
902	36.80	1.21	1.12	0.02
903	34.50	1.09	1.05	0.02
904	31.07	0.96	0.96	0.02
905	36.76	1.11	1.14	0.02
906	35.81	1.11	1.12	0.02
907	33.16	1.21	1.00	0.02
908	33.67	1.03	1.04	0.02
909	35.50	1.12	1.10	0.02
910	27.74	1.14	0.82	0.01
911	33.00	1.15	1.00	0.02
912	33.99	1.34	1.02	0.02
913	33.03	1.13	1.00	0.01
914	30.99	0.97	0.96	0.02
915	38.00	1.10	1.18	0.02
916	31.93	1.01	0.99	0.02
917	28.67	1.00	0.87	0.01
918	31.88	0.98	0.99	0.01
919	35.77	1.19	1.08	0.02
920	34.52	1.14	1.06	0.01
921	32.27	1.06	0.99	0.02
922	33.02	1.19	0.99	0.01
923	34.91	1.24	1.06	0.02
924	31.35	1.12	0.95	0.01
925	29.97	0.98	0.92	0.01
926	33.49	1.25	0.99	0.02
927	35.91	1.27	1.09	0.02
928	34.49	1.27	1.03	0.02
929	34.94	1.38	1.04	0.02
930	28.75	0.89	0.91	0.02
931	29.98	1.04	0.90	0.02
932	32.99	1.25	0.98	0.01
933	30.23	1.16	0.90	0.01
934	27.72	1.16	0.80	0.01
935	34.37	1.24	1.03	0.02
936	28.45	1.20	0.85	0.02
937	33.11	1.30	0.98	0.02
938	32.46	1.06	0.99	0.01
939	28.91	1.16	0.85	0.01
940	31.56	1.17	0.96	0.02
941	33.57	0.96	1.07	0.02
942	35.30	1.07	1.08	0.02
943	29.87	1.02	0.91	0.01
944	35.11	1.07	1.09	0.02
945	37.61	1.39	1.12	0.02
946	35.36	1.19	1.09	0.02
947	33.80	1.18	1.02	0.01
948	34.78	1.38	1.03	0.02
949	34.63	1.20	1.04	0.02
950	34.99	1.42	1.04	0.02
951	37.55	1.21	1.15	0.02
952	30.17	1.14	0.91	0.02
953	30.64	1.14	0.94	0.02
954	29.42	1.00	0.90	0.02
955	29.64	1.12	0.89	0.02
956	27.95	1.13	0.83	0.02
957	37.34	1.30	1.15	0.02
958	33.10	1.19	0.99	0.02
959	35.00	1.24	1.05	0.02
960	32.26	1.05	0.98	0.01
961	36.26	1.34	1.08	0.02
962	32.96	1.01	1.02	0.01
963	27.83	0.85	0.87	0.01
964	33.30	1.32	1.00	0.02
965	34.42	0.92	1.09	0.02
966	30.36	1.11	0.91	0.01
967	32.91	1.14	0.99	0.01
968	33.45	0.99	1.04	0.01
969	34.61	1.14	1.06	0.01
970	33.14	1.13	1.01	0.01

Mean Annual Temperature

Year (1901-1970)	Mean	Std Error of Mean	Mean Deviation	Std Error of Deviation
901	52.04	0.58	-0.32	0.11
902	51.78	0.64	-0.57	0.08
903	50.92	0.64	-1.44	0.08
904	50.74	0.68	-1.61	0.12
905	51.10	0.65	-1.26	0.09
906	52.11	0.63	-0.25	0.08
907	51.65	0.70	-0.71	0.12
908	52.84	0.65	0.48	0.08
909	51.75	0.69	-0.60	0.10
910	52.45	0.61	0.10	0.10
911	52.90	0.70	0.54	0.11
912	50.56	0.66	-1.79	0.11
913	52.76	0.64	0.41	0.10
914	52.35	0.62	-0.01	0.07
915	51.80	0.63	-0.55	0.08
916	51.31	0.71	-1.05	0.11
917	49.82	0.70	-2.53	0.11
918	52.48	0.64	0.12	0.07
919	52.28	0.66	-0.07	0.09
920	51.67	0.62	-0.69	0.05
921	54.93	0.63	2.58	0.08
922	53.18	0.67	0.83	0.10
923	52.40	0.64	0.05	0.07
924	50.59	0.66	-1.76	0.08
925	52.83	0.66	0.47	0.08
926	52.18	0.64	-0.18	0.11
927	52.54	0.70	0.19	0.10
928	52.48	0.61	0.12	0.07
929	51.23	0.68	-1.13	0.10
930	52.92	0.61	0.56	0.09
931	54.95	0.56	2.60	0.14
932	52.49	0.66	0.14	0.10
933	54.09	0.67	1.73	0.09
934	54.54	0.61	2.18	0.14
935	52.59	0.66	0.24	0.08
936	52.60	0.68	0.24	0.09
937	51.97	0.66	-0.39	0.08
938	54.29	0.64	1.93	0.07
939	54.17	0.63	1.81	0.08
940	51.88	0.59	-0.48	0.12
941	53.72	0.59	1.36	0.09
942	52.50	0.61	0.14	0.07
943	52.40	0.65	0.04	0.09
944	52.68	0.63	0.32	0.09
945	52.20	0.66	-0.16	0.08
946	53.94	0.63	1.58	0.08
947	52.32	0.61	-0.04	0.06
948	52.29	0.63	-0.07	0.08
949	52.81	0.64	0.46	0.13
950	51.14	0.70	-1.21	0.13
951	51.11	0.70	-1.24	0.13
952	53.00	0.62	0.65	0.07
953	54.08	0.59	1.72	0.08
954	53.98	0.63	1.62	0.09
955	52.53	0.64	0.17	0.08
956	52.92	0.65	0.56	0.08
957	52.59	0.63	0.23	0.07
958	51.78	0.56	-0.58	0.13
959	52.49	0.61	0.14	0.07
960	51.40	0.59	-0.96	0.08
961	52.02	0.57	-0.33	0.09
962	51.99	0.62	-0.37	0.07
963	52.45	0.57	0.10	0.14
964	52.46	0.61	0.11	0.10
965	52.04	0.65	-0.32	0.08
966	51.43	0.59	-0.92	0.09
967	51.70	0.61	-0.65	0.09
968	51.62	0.56	-0.74	0.11
969	51.33	0.59	-1.02	0.10
970	51.86	0.60	-0.50	0.08

APPENDIX H

Pearson Correlation Coefficients for each variable versus each other variable.

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHD=0 / N = 70

	AMNDF	WMNDF	SMNDF	AMXDF	WMXDF	SMXDF	AMIND	WMIND	SMIND	APCPT	SPCPT	WPCPT
AMNDF	1.00											
WMNDF	0.54	1.00										
SMNDF	0.63	0.24	1.00									
AMXDF	0.97	0.48	0.67	1.00								
WMXDF	0.54	0.97	0.25	0.50	1.00							
SMXDF	0.61	0.20	0.98	0.67	0.21	1.00						
AMIND	0.95	0.59	0.53	0.85	0.55	0.48	1.00					
WMIND	0.52	0.98	0.22	0.43	0.90	0.17	0.60	1.00				
SMIND	0.63	0.32	0.96	0.63	0.31	0.88	0.56	0.31	1.00			
APCPT	-0.26	0.02	-0.48	-0.42	-0.01	-0.54	-0.04	0.04	-0.35	1.00		
SPCPT	-0.39	0.01	-0.65	-0.49	-0.02	-0.74	-0.25	0.04	-0.45	0.64	1.00	
WPCPT	-0.17	0.04	-0.19	-0.20	-0.08	-0.19	-0.13	0.14	-0.16	0.11	0.22	1.00

A = Annual
W = Winter
S = Summer

MN = Mean Temperature
MX = Maximum Temperature
MI = Minimum Temperature

PCPT = Precipitation

Temperatures are calculated as a difference from the 70-year mean of the station (DF in titles signifies this).
Precipitation is calculated as a percentage of the 70-year mean of the station.

APPENDIX I

Graphs and Data for Regional Mean Series; Data for Overall Mean Series.

Temperature Data (°F)

Year	REGIONS 1	2	3	4	5	6	7	Mean*	Wtmean*
1901	52.1	45.7	50.6	42.9	62.3	49.0	51.2	52.0	52.3
1902	51.8	44.6	49.5	43.0	63.7	49.5	50.2	51.7	52.1
1903	51.9	43.6	47.8	41.2	62.5	49.1	49.6	50.9	51.2
1904	53.5	45.3	48.7	39.9	63.0	46.8	49.4	50.7	51.4
1905	52.8	44.6	48.7	41.4	63.1	48.6	49.5	51.1	51.6
1906	53.7	44.8	49.1	43.0	63.7	50.1	50.6	52.1	52.5
1907	52.2	45.3	50.4	41.0	64.6	48.2	50.1	51.6	52.2
1908	52.0	44.6	48.1	43.9	64.8	50.0	51.7	52.8	52.7
1909	51.2	44.5	48.9	42.3	64.5	49.4	50.1	51.7	52.0
1910	52.9	45.5	51.1	43.4	63.6	49.4	51.2	52.4	52.8
1911	50.9	43.0	48.8	43.0	65.6	50.4	51.8	52.9	52.7
1912	51.1	42.5	47.6	41.1	62.5	49.0	49.0	50.5	50.8
1913	51.6	42.9	48.1	43.3	64.2	51.7	51.8	52.7	52.5
1914	52.8	44.8	49.5	42.7	63.6	48.8	51.5	52.3	52.5
1915	53.2	44.7	48.5	43.1	63.8	50.0	50.0	51.8	52.2
1916	50.1	41.8	48.2	40.9	64.4	49.1	50.0	51.3	51.4
1917	52.1	42.9	47.9	38.9	62.5	47.1	48.2	49.8	50.5
1918	52.5	44.4	48.9	43.2	64.3	49.4	51.4	52.4	52.6
1919	51.5	43.8	48.9	43.0	64.6	50.5	50.8	52.2	52.4
1920	51.8	43.7	48.3	42.6	63.2	48.7	50.6	51.6	51.8
1921	52.9	45.5	51.2	45.7	66.3	52.0	54.3	54.9	54.6
1922	51.4	43.6	48.8	43.6	65.4	50.4	52.3	53.1	52.9
1923	52.3	43.2	47.9	43.2	64.2	49.3	51.5	52.4	52.3
1924	52.2	43.2	48.8	40.7	62.7	48.3	49.0	50.5	51.2
1925	53.6	45.1	49.7	42.6	65.0	49.8	51.7	52.8	53.1
1926	54.8	45.8	50.5	41.6	63.5	48.0	51.2	52.1	52.7
1927	52.1	43.7	50.1	41.8	65.6	50.2	51.1	52.5	52.8
1928	53.0	44.0	49.9	43.0	63.6	49.8	51.5	52.4	52.6
1929	52.3	42.8	48.4	41.1	63.9	50.1	49.4	51.2	51.6
1930	52.1	43.8	48.0	44.0	63.8	50.7	52.2	52.9	52.8
1931	53.6	45.1	49.8	47.2	64.8	52.2	54.6	54.9	54.4
1932	52.2	42.9	48.5	43.0	64.7	51.3	51.1	52.4	52.5
1933	52.3	44.8	49.5	43.6	66.1	51.1	53.5	54.0	53.7
1934	55.2	48.8	53.5	44.1	65.0	49.6	54.1	54.5	54.8
1935	52.0	44.2	50.3	42.4	64.7	49.8	51.5	52.5	52.8
1936	53.0	45.1	50.6	41.4	64.5	50.1	51.5	52.6	52.9
1937	52.3	44.1	49.9	41.9	64.1	50.5	50.4	51.9	52.4
1938	52.5	45.7	50.3	44.4	65.7	51.2	53.7	54.2	54.0
1939	53.6	46.1	50.6	44.2	65.4	50.4	53.6	54.1	54.0
1940	54.1	47.7	51.4	42.3	62.5	48.2	50.6	51.8	52.6
1941	53.1	46.0	49.8	45.0	64.6	50.9	52.9	53.7	53.6
1942	52.2	43.6	49.3	43.8	64.0	50.6	51.2	52.5	52.6
1943	52.0	44.9	51.1	42.5	64.3	49.4	51.1	52.4	52.7
1944	51.9	43.6	48.2	44.4	64.5	50.3	51.6	52.6	52.6
1945	52.5	44.3	49.0	42.5	64.8	50.7	50.5	52.2	52.5

*Mean is mean annual temperature for 144 U.S. stations.
*Wtmean is area-weighted mean annual temperature for 144 U.S. stations.

Temperature Data (°F) (cont)

Year	1	2	3	4	5	6	7	Mean*	Wtmean*
	REGIONS								
1946	52.3	45.0	50.3	44.2	65.1	51.4	53.3	53.9	53.7
1947	52.7	44.5	49.8	43.2	63.5	50.1	51.1	52.3	52.5
1948	50.4	43.3	49.1	43.6	64.1	50.1	51.1	52.2	52.2
1949	51.0	43.6	47.8	44.5	64.7	52.3	51.3	52.8	52.6
1950	51.8	44.1	50.5	40.3	63.9	49.8	49.2	51.1	51.8
1951	52.0	43.0	49.2	41.2	64.5	50.3	49.0	51.1	51.8
1952	52.0	44.6	48.9	44.4	64.5	50.9	52.0	53.0	52.9
1953	52.8	46.6	50.4	45.4	65.0	51.9	53.3	54.0	54.0
1954	51.7	45.7	51.1	44.4	65.4	50.3	53.5	53.9	53.8
1955	50.4	42.6	48.3	43.5	64.3	50.3	51.7	52.5	52.2
1956	51.3	44.3	49.8	43.2	64.7	49.5	52.3	52.9	52.8
1957	51.5	44.4	49.3	43.6	64.4	50.8	51.4	52.5	52.7
1958	54.3	47.0	50.6	43.4	62.3	48.4	50.5	51.7	52.5
1959	52.6	44.7	50.2	43.6	63.7	50.8	51.3	52.4	52.8
1960	52.1	44.8	49.9	43.2	62.5	49.2	50.0	51.4	51.9
1961	52.9	45.5	49.3	44.5	63.1	49.7	50.6	52.0	52.4
1962	51.7	44.8	49.4	43.3	63.8	48.5	50.9	51.9	52.2
1963	52.0	45.6	50.0	43.9	62.9	48.3	52.0	52.4	52.5
1964	51.1	42.9	47.3	44.1	63.6	49.4	52.0	52.4	52.1
1965	51.9	44.9	48.9	42.2	64.0	48.9	51.1	52.0	52.2
1966	52.7	45.6	49.7	42.3	62.4	48.8	50.2	51.4	52.0
1967	52.8	45.8	49.1	42.6	63.2	48.3	50.5	51.7	52.1
1968	52.2	44.2	48.1	43.8	62.0	48.5	50.8	51.6	51.7
1969	51.6	45.2	49.7	42.8	62.5	48.6	50.1	51.3	51.8
1970	51.9	44.6	49.1	43.0	62.9	48.9	51.0	51.8	52.0

*Mean is mean annual temperature for 144 U.S. stations.
*Wtmean is area-weighted mean annual temperature for 144 U.S. stations.

Precipitation Data (in.)

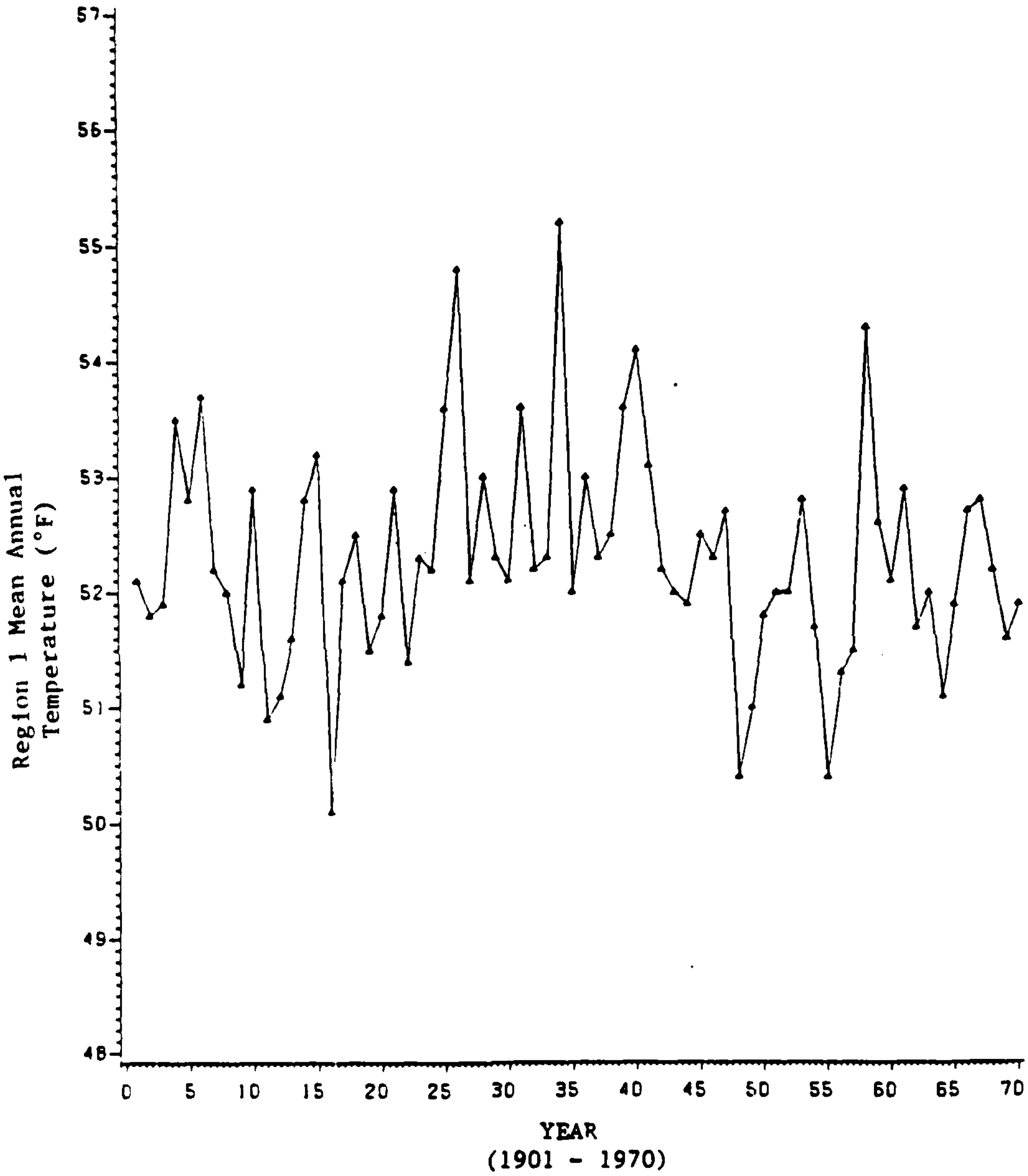
	REGIONS							
Year	1	2	3	4	5	6	Mean*	Wtmean*
1901	22.61	15.60	47.11	45.67	31.17	26.67	30.33	27.74
1902	22.08	17.29	47.26	46.58	36.60	40.34	36.80	31.59
1903	20.65	17.37	49.05	43.94	36.76	34.68	34.50	30.12
1904	23.89	16.22	40.14	37.49	31.59	32.66	31.07	27.83
1905	18.18	20.35	50.16	39.55	39.09	39.92	36.76	31.48
1906	27.74	22.15	48.71	41.77	38.93	34.76	35.81	32.86
1907	25.18	17.12	50.20	43.10	35.83	30.71	33.16	30.17
1908	17.82	18.75	49.20	37.63	34.32	35.62	33.67	29.31
1909	25.90	19.14	47.27	38.77	38.86	36.75	35.50	31.64
1910	18.37	11.92	44.35	36.38	30.92	25.78	27.74	24.48
1911	21.71	16.85	46.45	41.01	38.09	31.63	33.00	29.11
1912	22.11	17.57	62.68	41.05	35.73	30.34	33.99	30.99
1913	21.05	18.32	47.91	43.19	36.51	31.01	33.01	29.46
1914	19.72	21.03	48.44	37.64	32.97	28.29	30.99	28.51
1915	22.68	20.44	50.18	38.88	40.14	41.92	38.00	32.91
1916	23.87	18.83	43.75	39.11	36.87	29.66	31.93	29.02
1917	18.57	13.61	40.63	37.84	31.76	27.83	28.67	25.14
1918	20.77	18.25	44.57	40.17	33.08	31.71	31.88	28.48
1919	19.34	22.05	52.35	44.18	38.09	34.84	35.77	31.69
1920	23.13	19.05	52.23	42.90	34.68	34.07	34.52	31.07
1921	22.45	17.55	42.52	37.34	37.44	31.96	32.27	28.61
1922	20.42	17.37	53.41	39.06	34.84	31.92	33.02	29.45
1923	18.41	19.37	53.68	39.38	34.75	36.61	34.91	30.56
1924	16.95	16.09	50.44	40.41	33.52	29.73	31.35	27.53
1925	19.46	15.70	42.98	38.81	31.63	29.44	29.97	26.58
1926	20.01	17.08	50.75	39.40	39.60	31.62	33.49	28.38
1927	24.12	19.26	40.15	45.43	39.60	37.71	35.91	31.26
1928	17.30	16.26	54.20	41.02	35.59	36.60	34.49	29.63
1929	15.50	17.71	60.83	41.55	36.66	34.05	34.94	30.30
1930	17.02	19.19	46.30	28.55	26.26	30.47	28.75	26.16
1931	19.45	15.17	38.34	36.90	31.57	31.68	29.98	26.13
1932	19.65	17.68	53.19	40.86	34.80	31.49	32.99	29.40
1933	20.89	13.72	42.48	42.42	32.10	29.36	30.23	26.66
1934	17.95	11.79	47.69	38.54	28.85	25.28	27.72	24.68
1935	17.45	19.53	45.99	41.36	39.06	34.62	34.37	29.62
1936	21.03	18.44	51.05	40.89	29.38	22.25	28.45	27.13
1937	24.82	16.90	49.90	45.80	36.54	28.57	33.11	30.06
1938	22.27	16.45	41.68	41.65	36.57	32.23	32.46	28.54
1939	15.39	14.38	47.82	36.35	32.27	26.84	28.91	25.31
1940	25.96	18.82	51.44	42.80	30.26	28.37	31.56	29.85
1941	24.96	22.18	48.88	32.34	34.81	34.33	33.57	30.96
1942	23.62	19.52	45.87	44.69	38.42	35.35	35.30	31.28
1943	18.13	15.99	45.84	39.49	32.97	27.54	29.87	26.55
1944	18.67	22.96	52.96	39.10	34.96	35.97	36.11	31.33
1945	25.54	17.79	53.11	49.93	38.85	37.60	37.61	33.17

*Mean is mean annual total precipitation for 144 U.S. stations.
*Wtmean is area-weighted mean annual total precipitation for 144 U.S. stations.

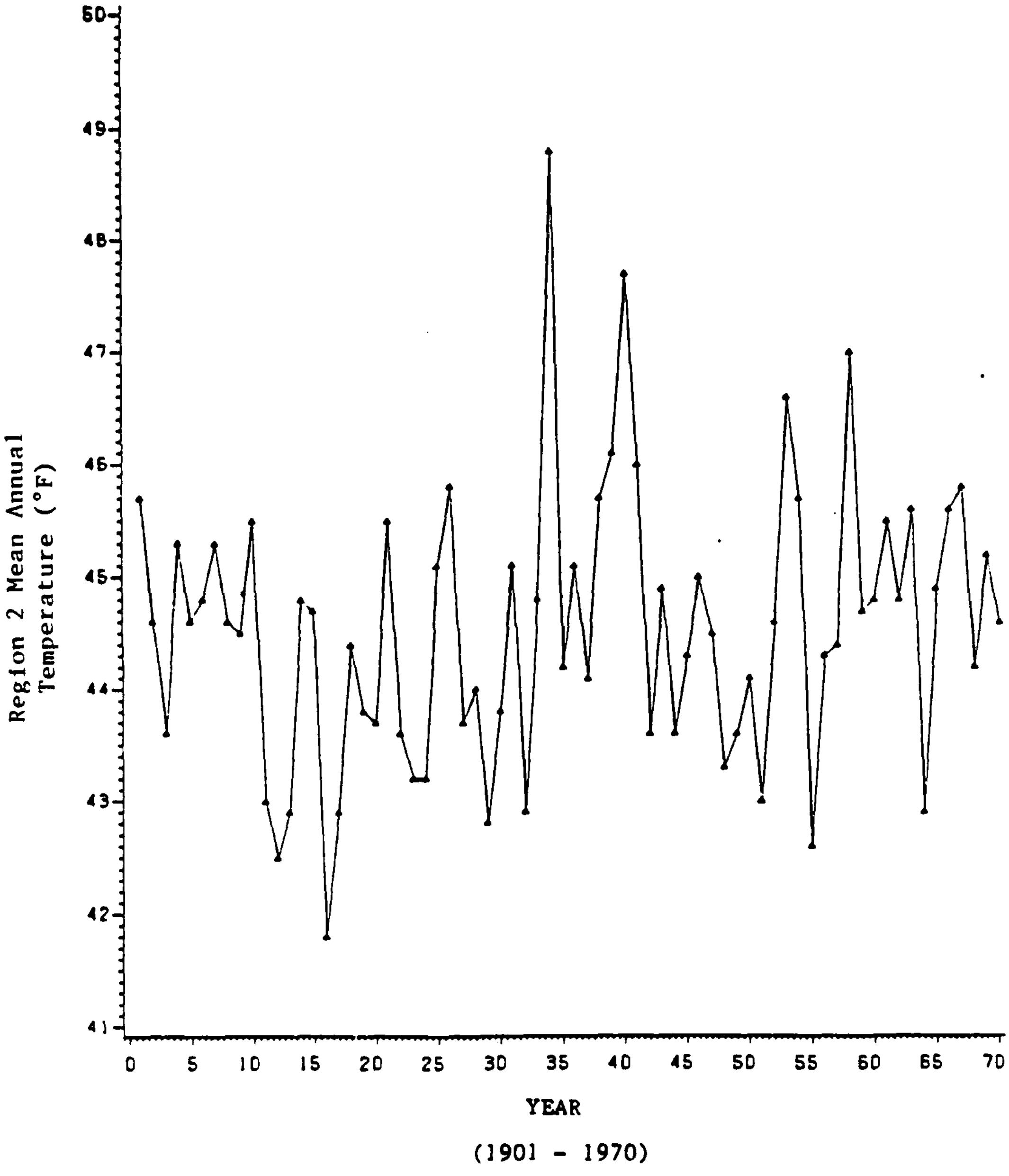
Precipitation Data (in.) (cont)

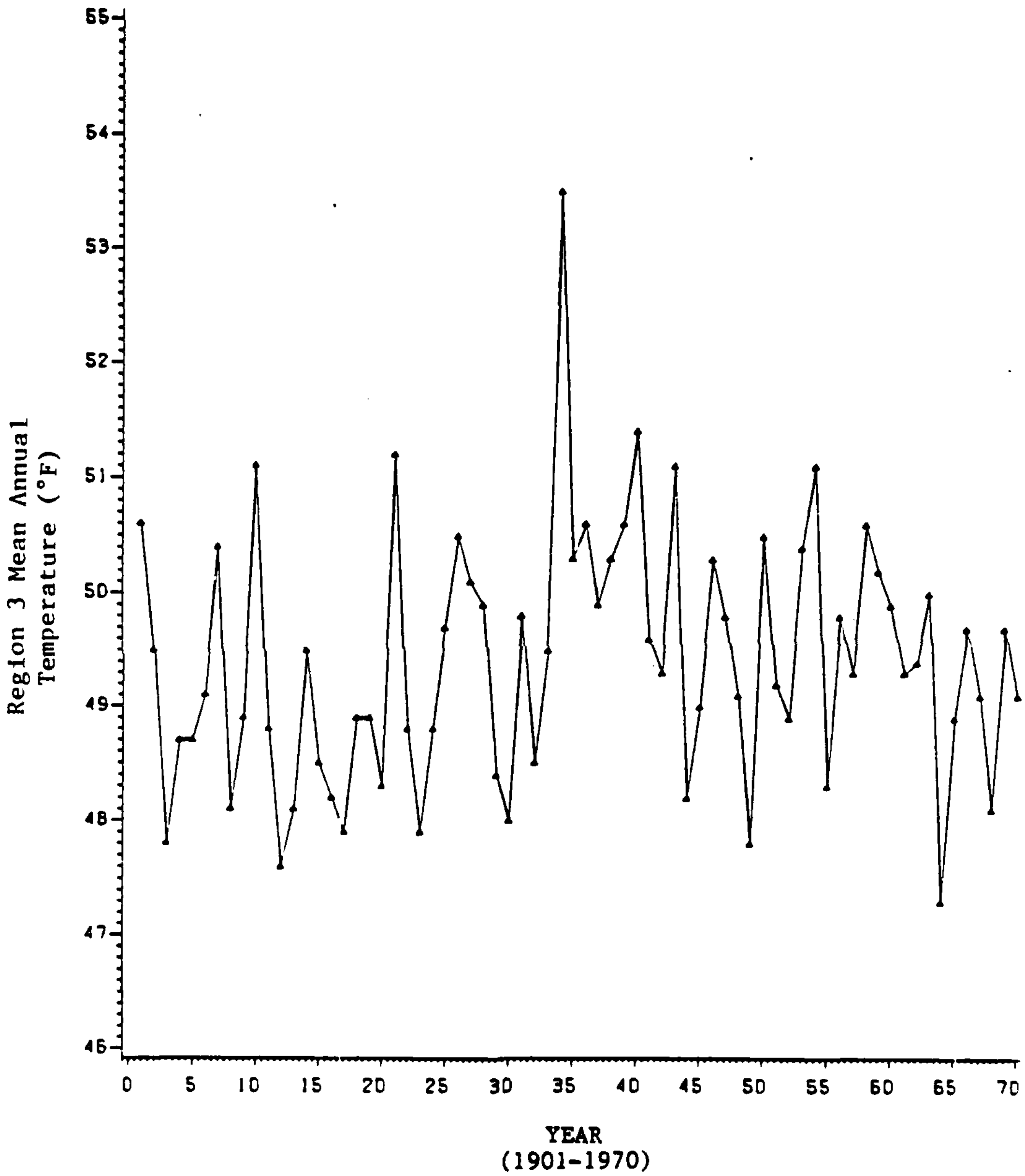
	REGIONS							
Year	1	2	3	4	5	6	Mean*	Wtmean*
1946	20.02	21.20	57.00	36.83	36.97	35.44	35.36	31.57
1947	20.12	17.61	58.12	40.51	33.25	33.02	33.80	30.26
1948	25.53	16.13	58.90	44.58	36.03	32.18	34.78	31.58
1949	19.18	17.89	48.94	38.64	37.36	36.41	34.63	29.90
1950	27.84	15.87	46.03	44.59	39.11	34.83	34.99	31.15
1951	24.86	17.51	43.55	45.96	39.50	41.59	37.55	32.23
1952	20.32	16.54	43.43	44.31	31.83	27.50	30.17	27.16
1953	21.96	17.93	53.67	40.02	33.31	25.52	30.64	28.54
1954	21.72	14.78	31.48	43.56	32.76	29.16	29.42	25.80
1955	26.02	14.40	46.19	38.94	33.94	25.53	29.64	27.47
1956	20.01	13.10	41.45	41.65	32.98	23.60	27.95	25.02
1957	22.83	22.97	54.18	35.67	39.50	39.48	37.34	33.26
1958	24.92	16.46	49.47	42.33	31.73	33.41	33.10	29.94
1959	19.64	17.83	58.82	42.58	35.49	34.17	35.00	30.96
1960	21.55	17.94	51.32	39.35	32.11	31.48	32.26	29.22
1961	21.24	17.57	55.57	41.34	36.68	38.08	36.26	31.64
1962	23.39	19.67	48.15	38.23	34.83	32.27	32.96	29.99
1963	23.13	16.08	43.75	33.08	28.83	25.94	27.83	26.03
1964	25.52	17.67	62.35	33.93	34.91	30.58	33.30	31.02
1965	21.42	21.44	48.56	32.47	36.84	36.55	34.42	30.67
1966	19.32	16.43	50.97	36.91	34.38	27.04	30.36	27.39
1967	23.24	16.55	47.13	41.32	36.66	32.17	32.91	29.35
1968	25.35	21.67	44.33	38.06	35.29	33.44	33.45	30.70
1969	24.63	20.36	51.94	41.42	34.90	34.04	34.61	31.58
1970	26.81	17.20	48.83	39.21	37.45	31.12	33.14	30.26

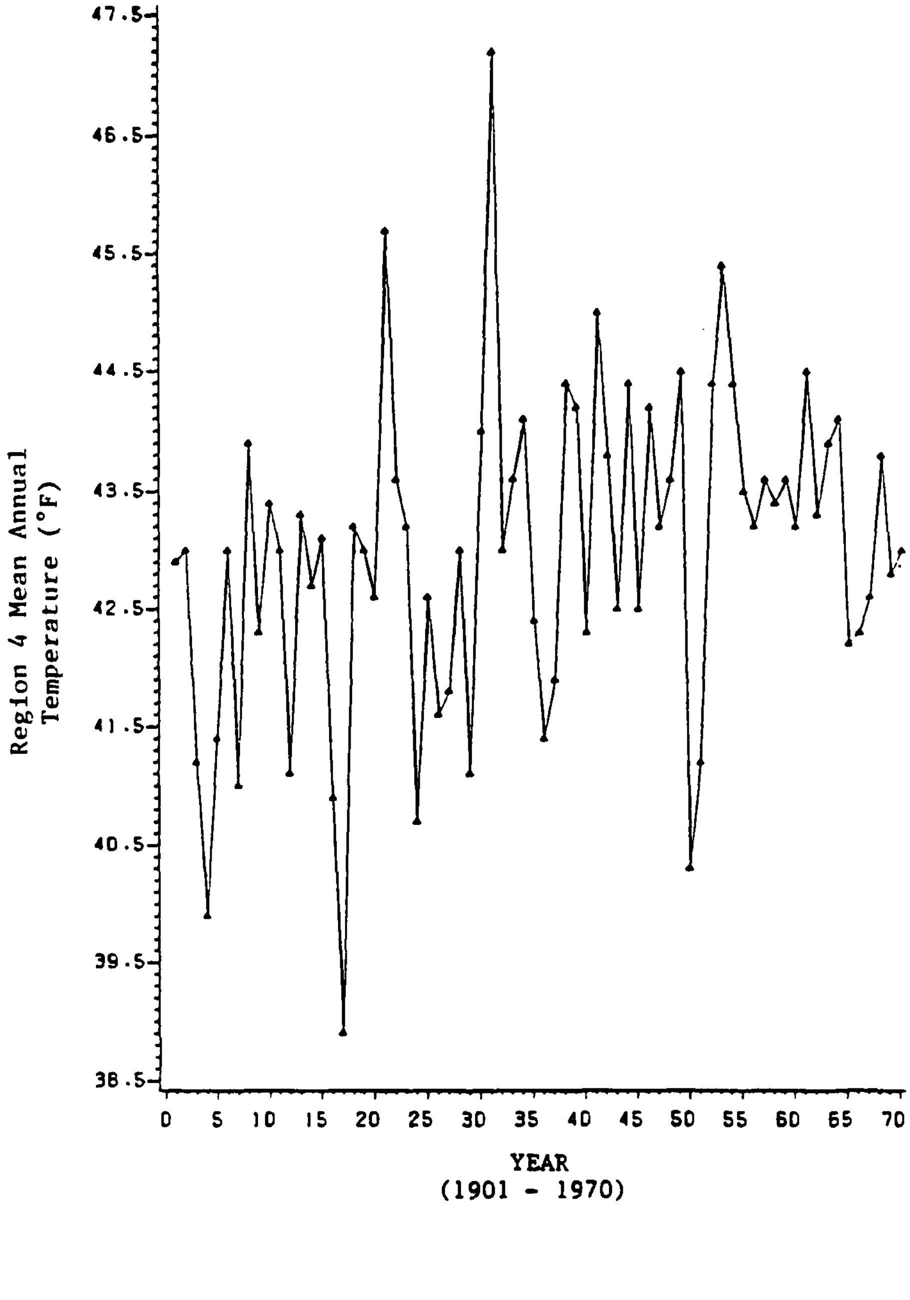
*Mean is mean annual total precipitation for 144 U.S. stations.
*Wtmean is area-weighted mean annual total precipitation for 144 U.S. stations.

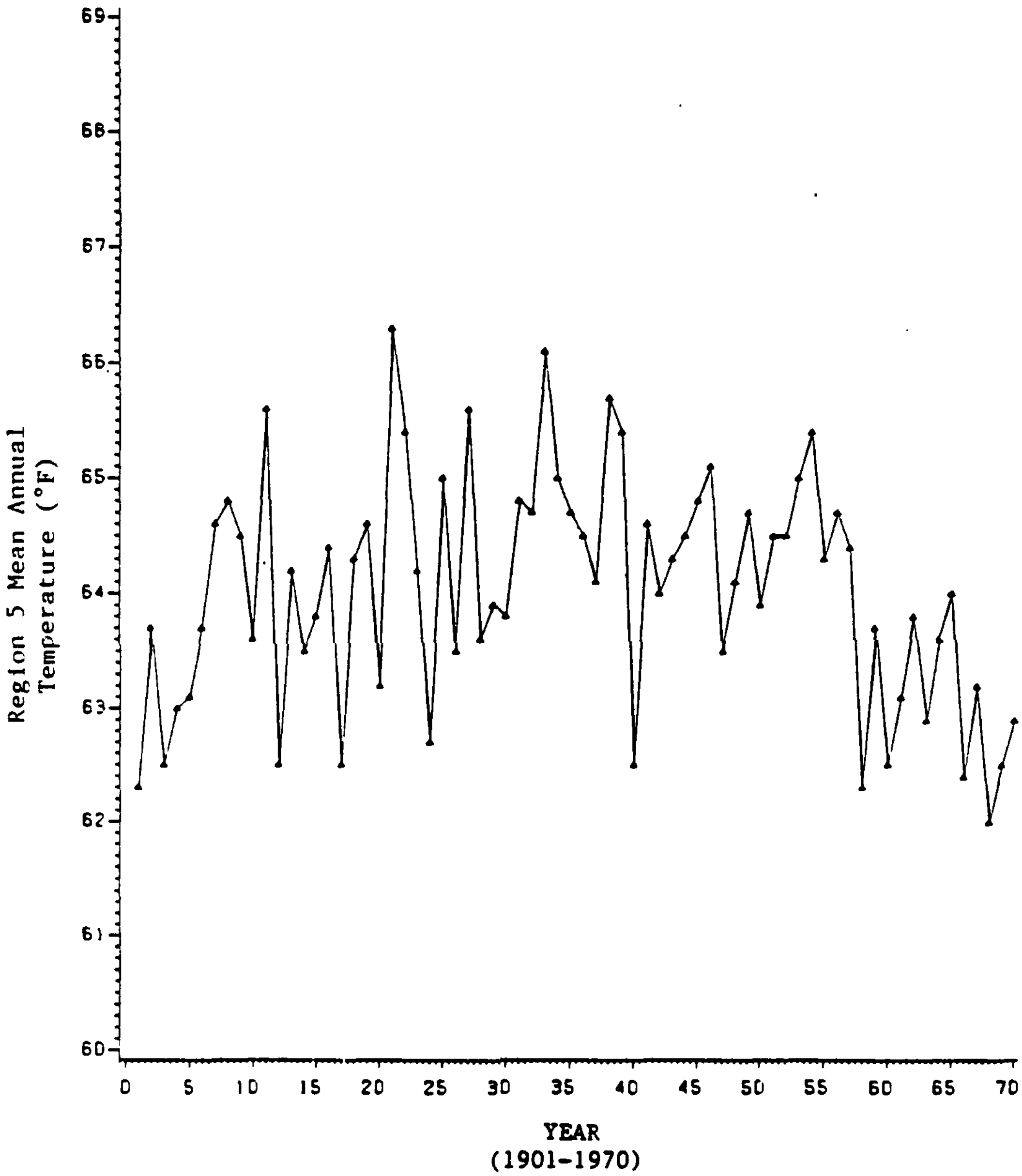


Region 1 Mean Annual Temperature (°F)
57
56
55
54
53
52
51
50
49
48
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)

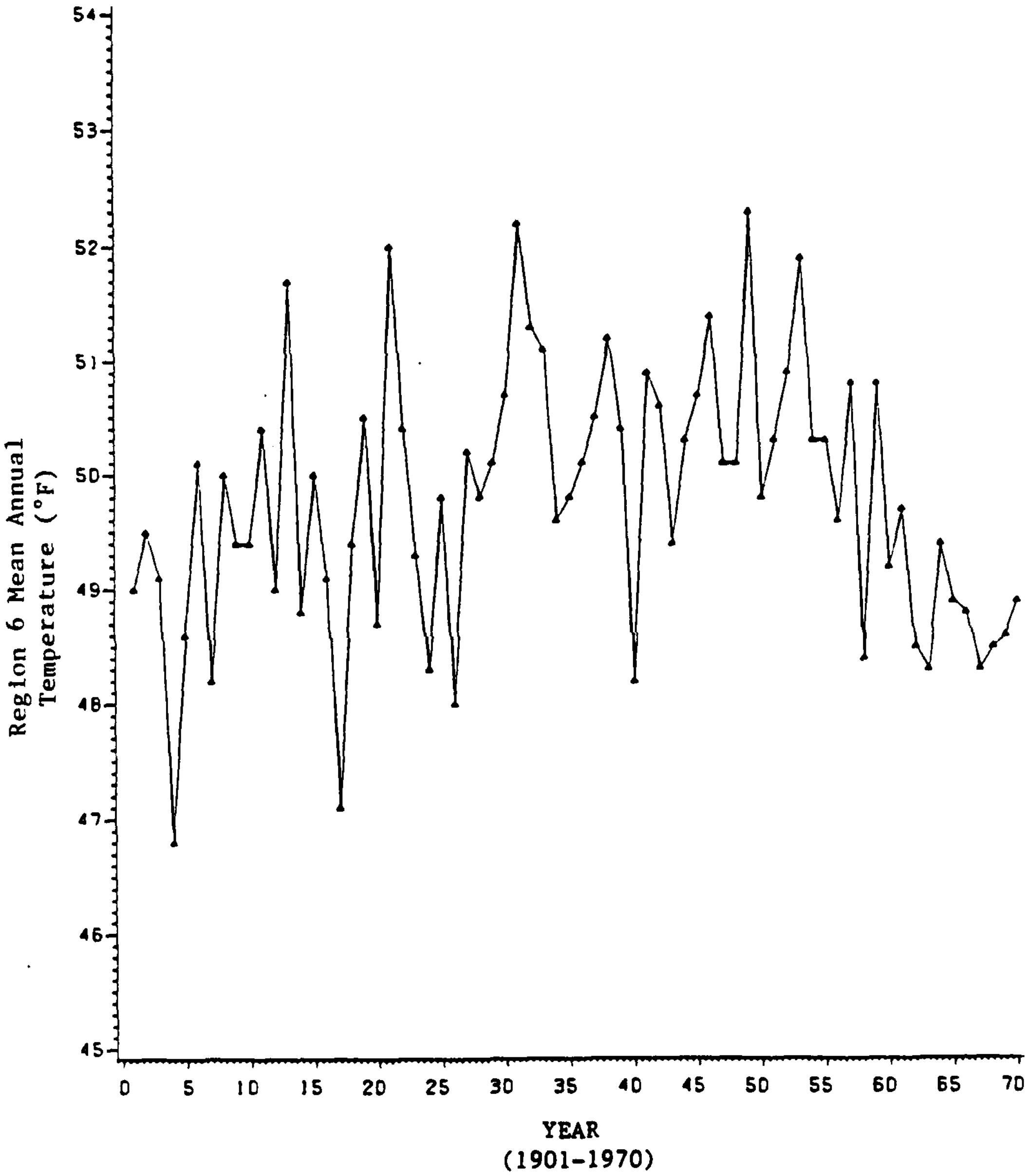

Region 2 Mean Annual
Temperature (°F)
50
49
48
47
46
45
44
43
42
41
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)

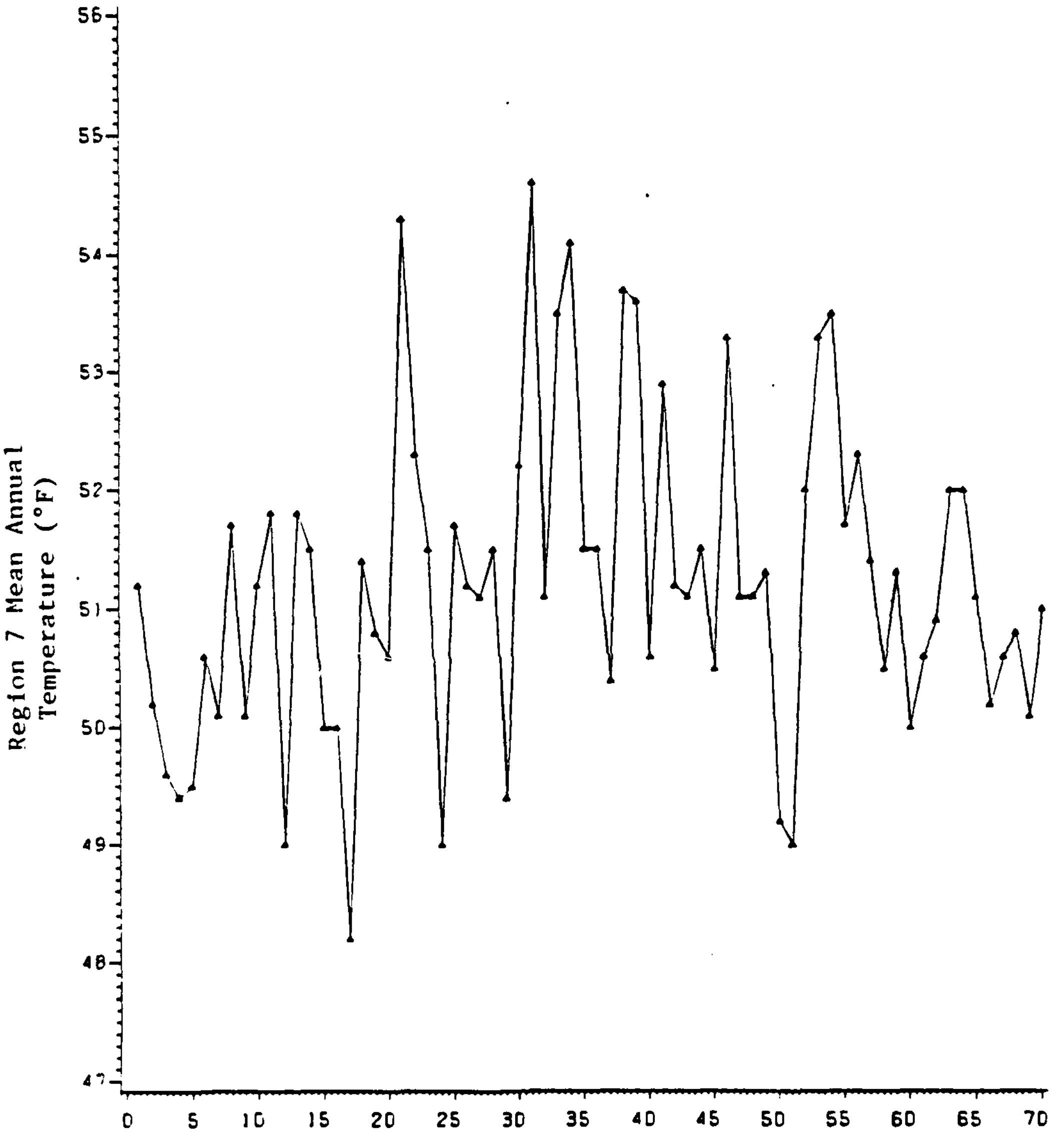

55
54
53
52
51
50
49
48
47
46
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Region 3 Mean Annual Temperature (°F)
YEAR
(1901-1970)


Region 4 Mean Annual
Temperature (°F)
47.5
46.5
45.5
44.5
43.5
42.5
41.5
40.5
39.5
38.5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
YEAR
(1901 - 1970)

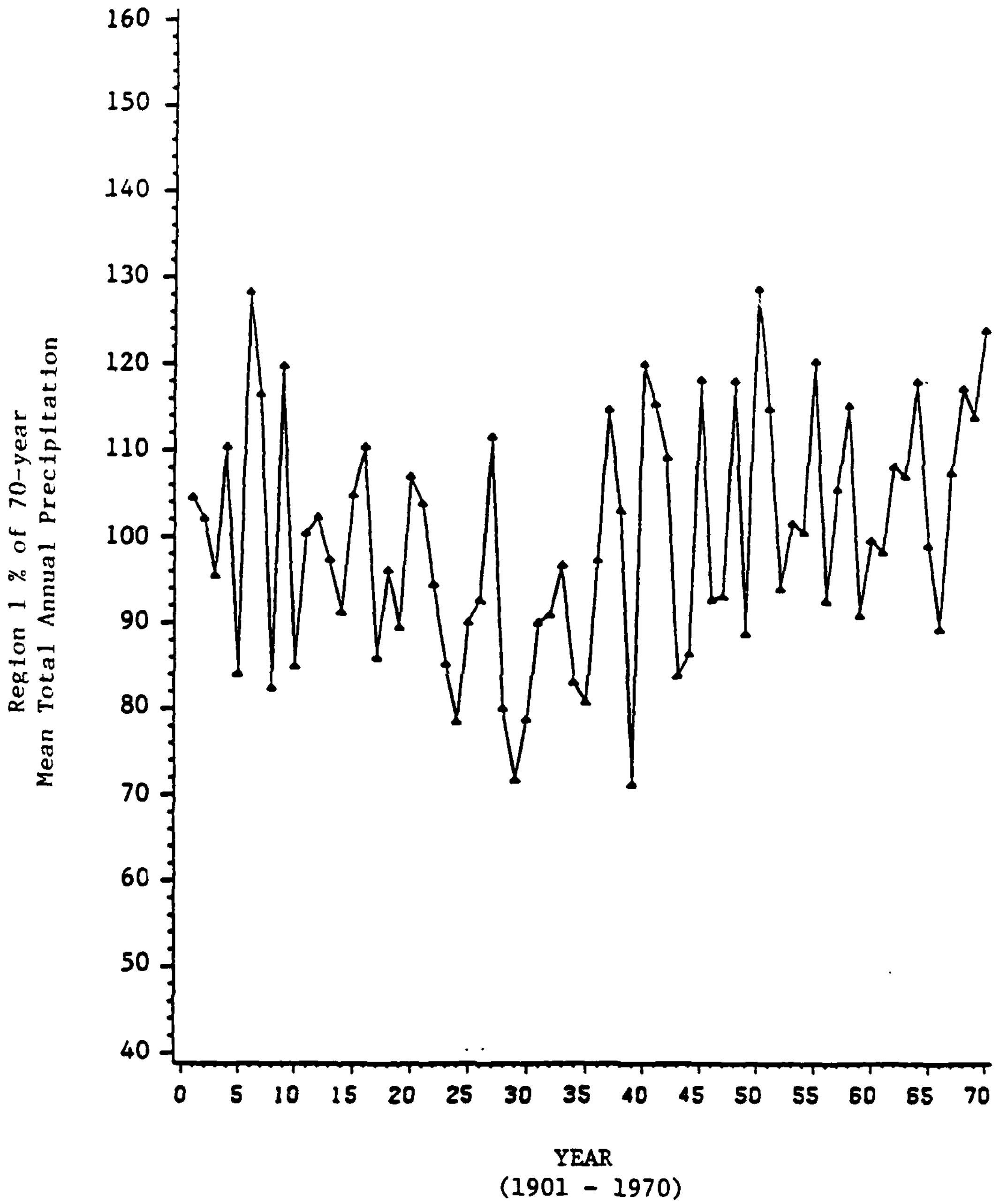


Region 5 Mean Annual Temperature (°F)
69
68
67
66
65
64
63
62
61
60
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901-1970)

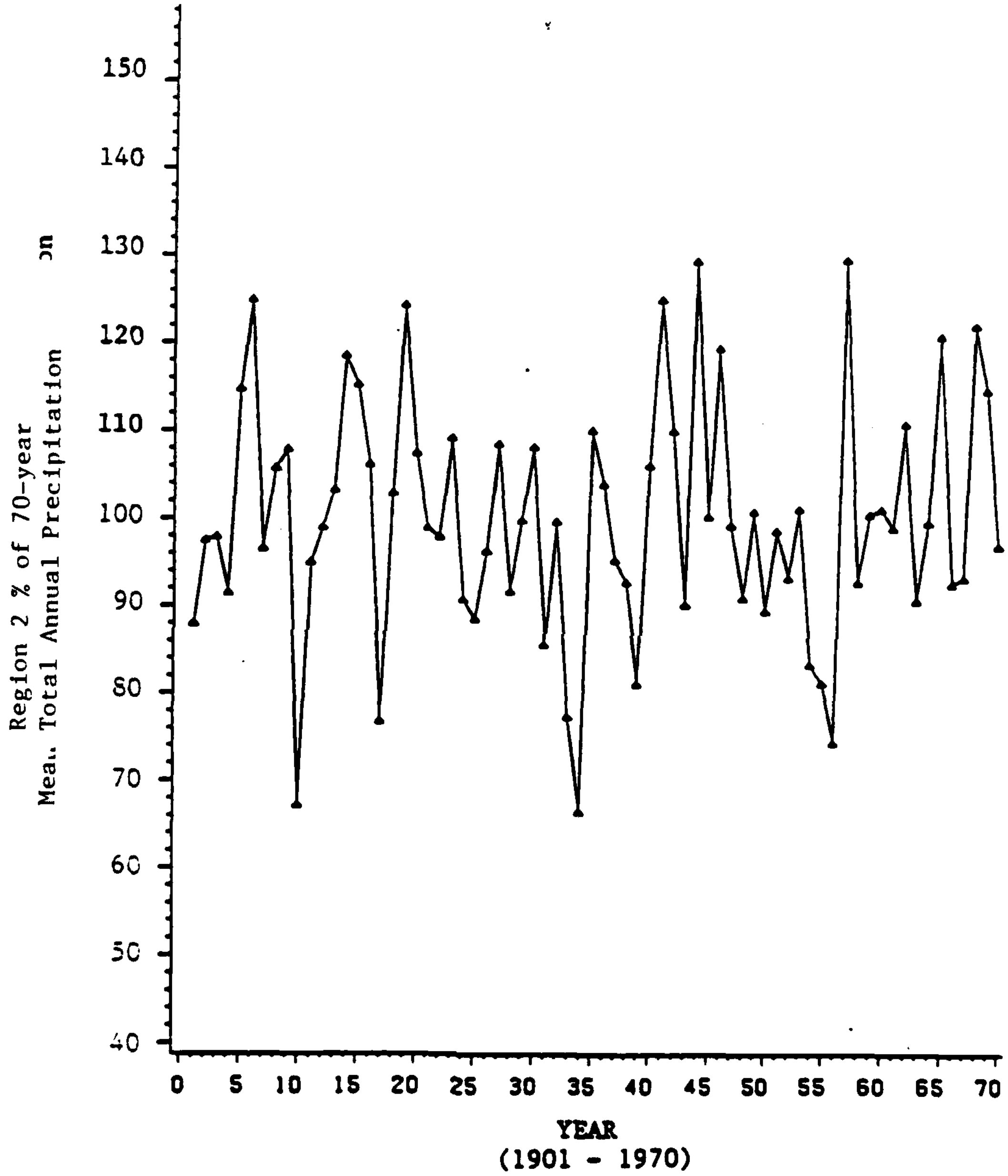

Region 6 Mean Annual
Temperature (°F)
54
53
52
51
50
49
48
47
46
45
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901-1970)

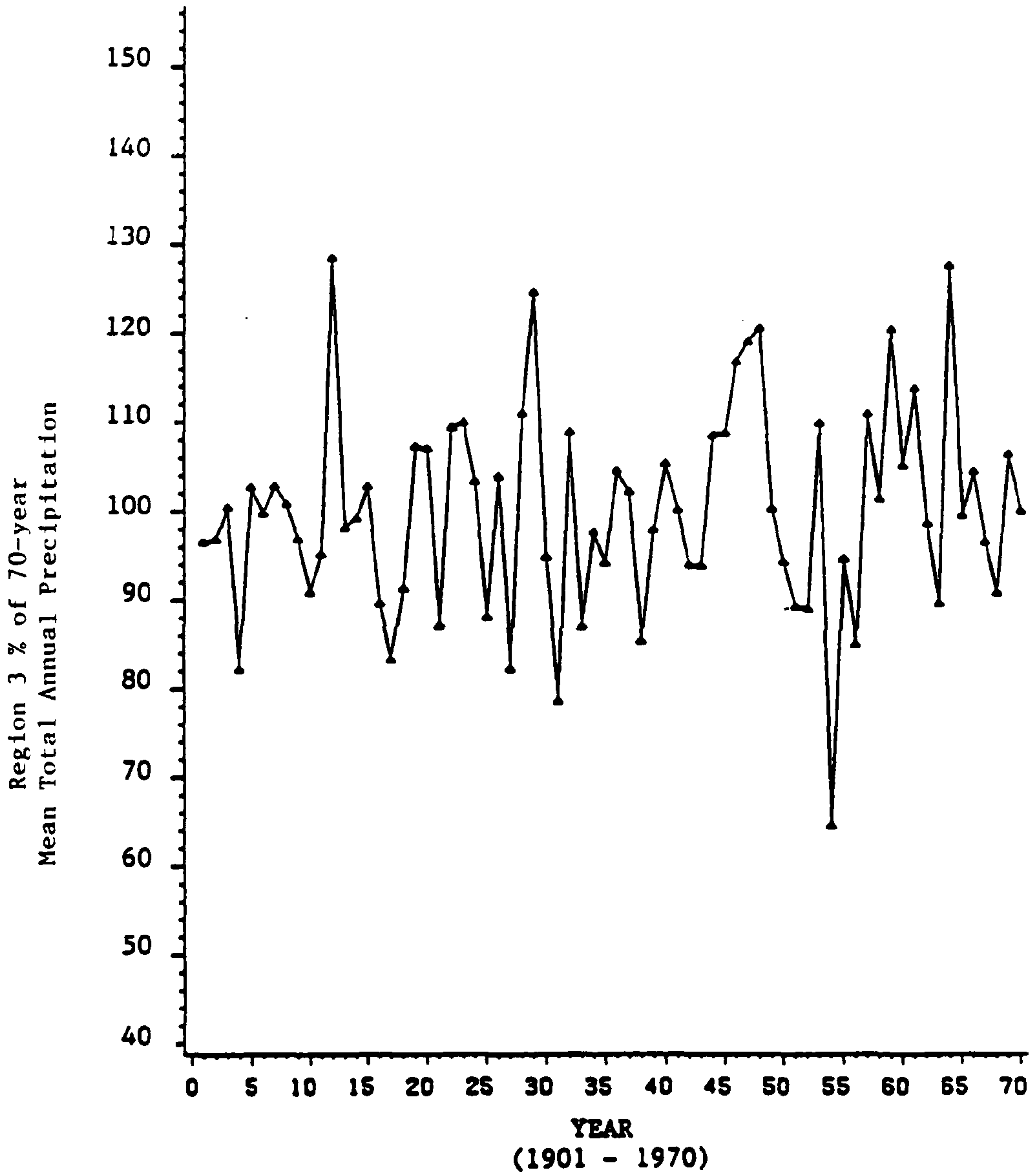


YEAR
(1901 - 1970)

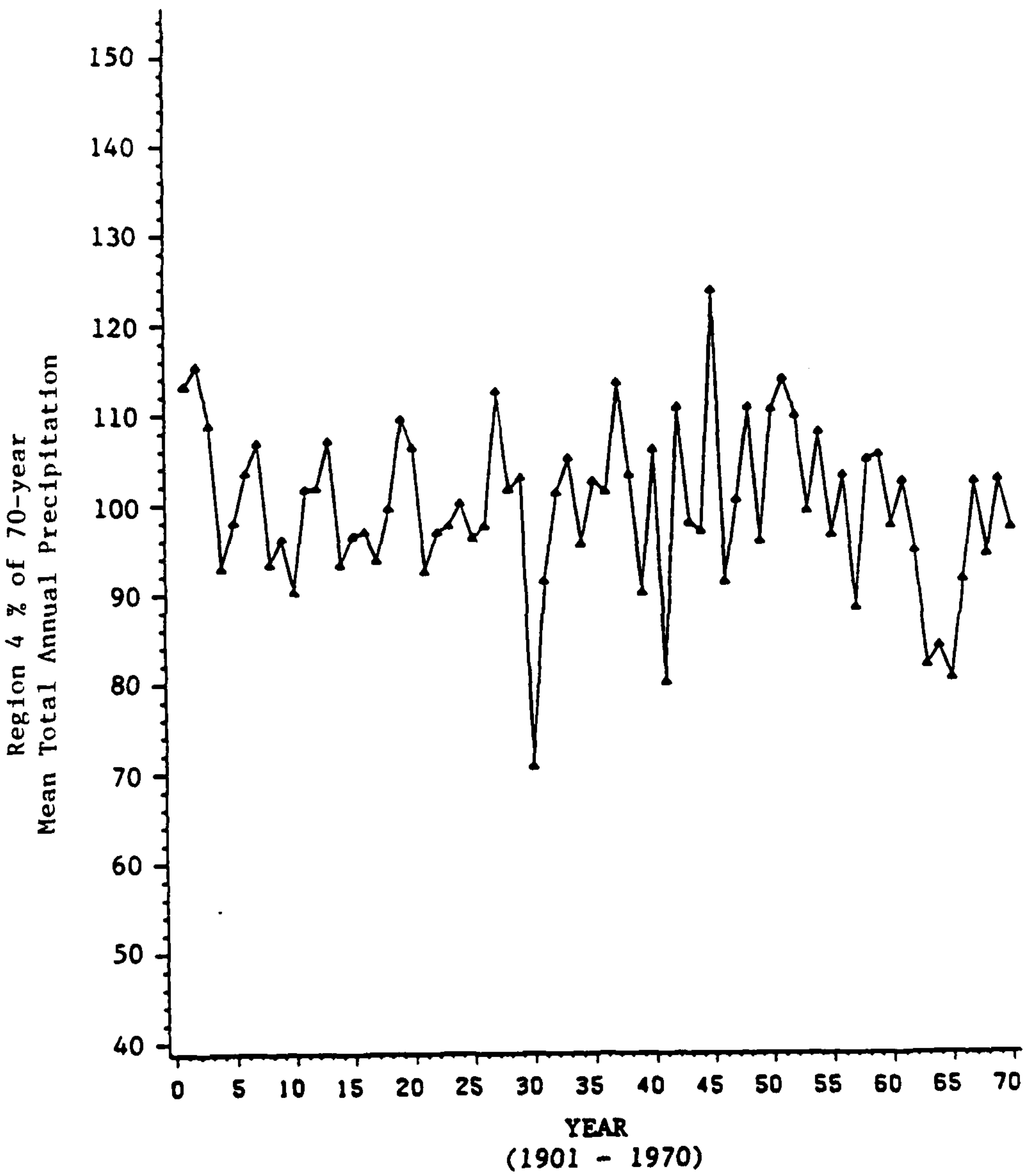


Region 1 % of 70-year
Mean Total Annual Precipitation
160
150
140
130
120
110
100
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)

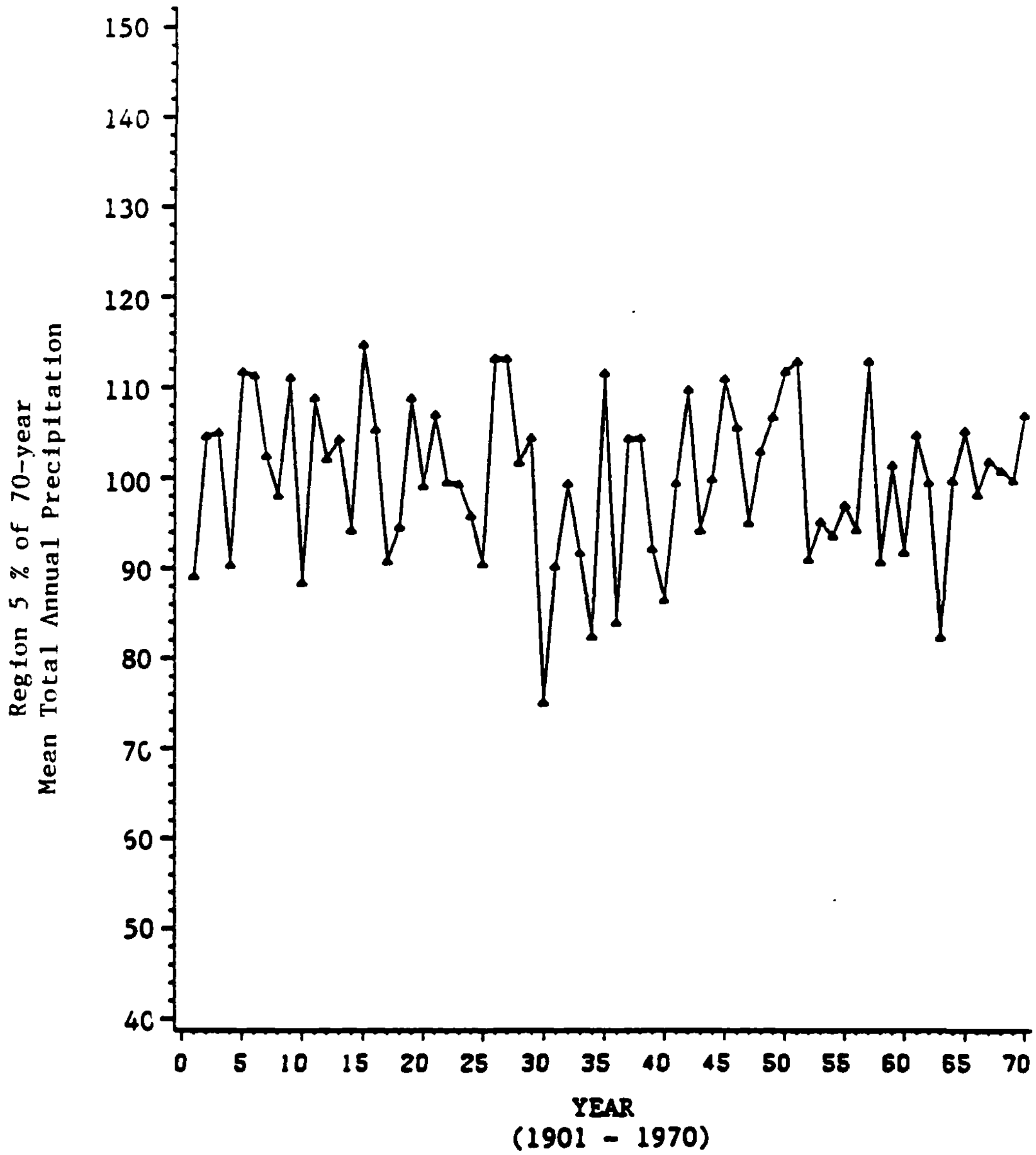

150
140
130
120
110
100
90
80
70
60
50
40
Region 2 % of 70-year
Mea.. Total Annual Precipitation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
YEAR
(1901 - 1970)



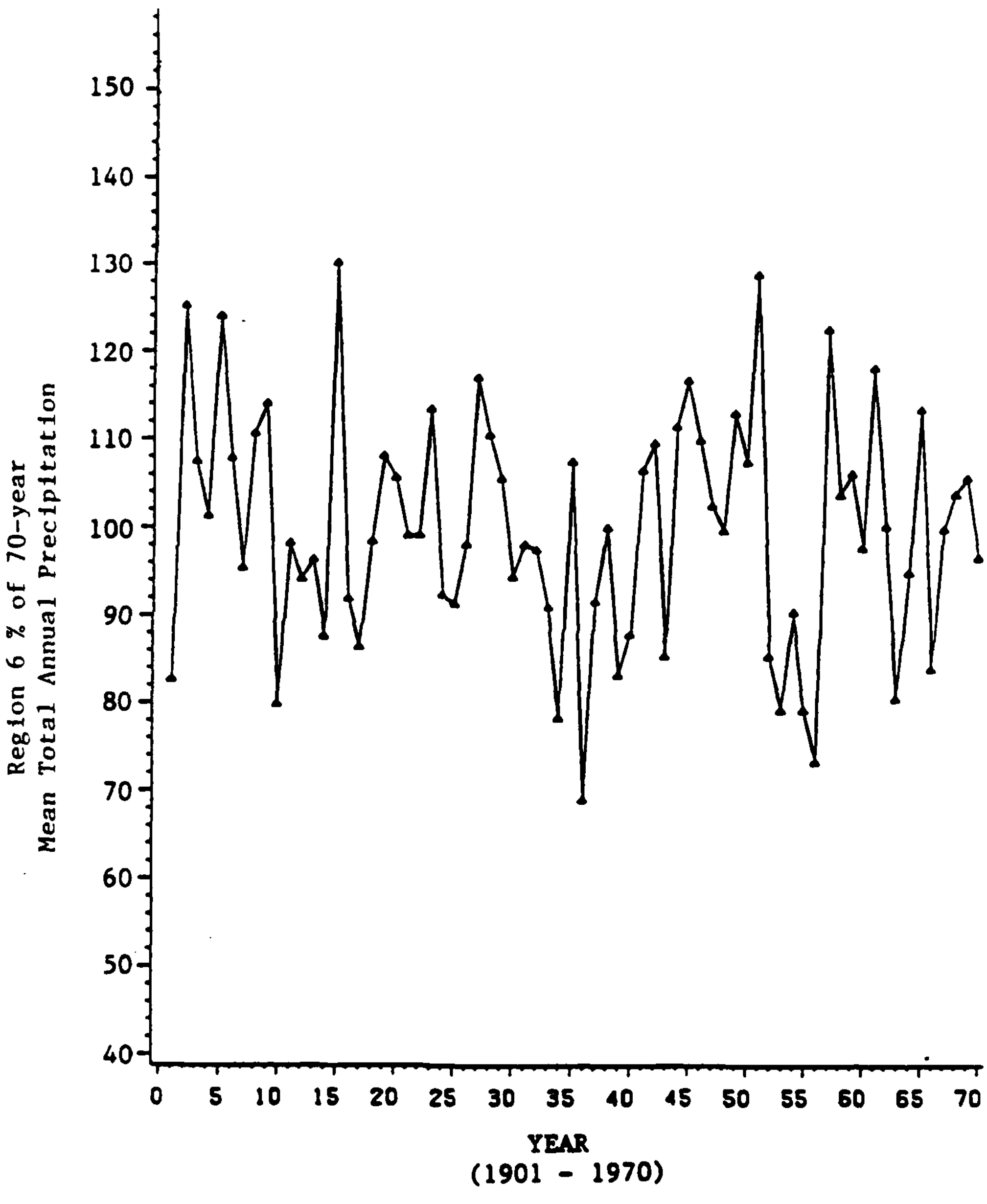
Region 3 % of 70-year
Mean Total Annual Precipitation
150
140
130
120
110
100
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)



Region 4 % of 70-year
Mean Total Annual Precipitation
150
140
130
120
110
100
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)



150
140
130
120
110
100
90
80
70
60
50
40
Region 5 % of 70-year
Mean Total Annual Precipitation
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
YEAR
(1901 - 1970)


Region 6 % of 70-year
Mean Total Annual Precipitation
150
140
130
120
110
100
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
YEAR
(1901 - 1970)

APPENDIX J

Simple Statistics for Regional and area-weighted mean series.

Variable	Mean	Standard Deviation	Std Error of Mean
Decade = 1			
DIFMEAN	3.81	0.96	0.30
WTMEAN	29.72	2.48	0.79
GP1	22.24	3.48	1.10
GP2	17.59	2.80	0.89
GP3	47.34	3.08	0.97
GP4	41.09	3.63	1.15
GP5	35.41	3.25	1.03
GP6	33.74	4.95	1.57
MEAN	33.53	3.00	0.95
Decade = 2			
DIFMEAN	3.54	0.72	0.23
WTMEAN	29.64	2.17	0.69
GP1	21.30	1.73	0.55
GP2	18.60	2.37	0.75
GP3	48.92	6.10	1.93
GP4	40.60	2.28	0.72
GP5	35.79	2.67	0.84
GP6	32.09	4.11	1.30
MEAN	33.18	2.60	0.82
Decade = 3			
DIFMEAN	3.96	0.70	0.22
WTMEAN	28.95	1.71	0.54
GP1	19.16	2.68	0.85
GP2	17.56	1.35	0.43
GP3	49.53	6.45	2.04
GP4	39.09	4.30	1.36
GP5	34.98	3.96	1.25
GP6	32.87	2.92	0.92
MEAN	32.91	2.33	0.74
Decade = 4			
DIFMEAN	3.24	1.03	0.33
WTMEAN	27.74	2.00	0.63
GP1	20.49	3.26	1.03
GP2	16.29	2.49	1.79
GP3	46.96	4.82	1.52
GP4	40.76	2.84	0.90
GP5	33.14	3.44	1.09
GP6	29.11	3.66	1.16
MEAN	30.98	2.25	0.71
Decade = 5			
DIFMEAN	3.73	0.61	0.19
WTMEAN	30.77	1.72	0.54
GP1	22.36	3.51	1.11
GP2	18.71	2.62	0.83
GP3	51.56	5.17	1.63
GP4	41.08	4.99	1.58
GP5	36.27	2.23	0.71
GP6	34.21	2.85	0.90
MEAN	34.50	1.96	0.62
Decade = 6			
DIFMEAN	3.35	0.96	0.30
WTMEAN	28.96	2.70	0.85
GP1	22.38	2.23	0.70
GP2	16.96	2.69	0.85
GP3	47.36	7.86	2.49
GP4	41.44	3.00	0.95
GP5	34.31	2.95	0.93
GP6	31.12	6.05	1.91
MEAN	32.31	3.37	1.07
Decade = 7			
DIFMEAN	3.06	0.78	0.25
WTMEAN	29.86	1.83	0.58
GP1	23.40	2.28	0.72
GP2	18.46	2.13	0.67
GP3	50.16	5.52	1.75
GP4	37.60	3.44	1.09
GP5	34.98	2.39	0.75
GP6	32.12	3.77	1.19
MEAN	32.92	2.34	0.74

Legend of Variable Names:

DIFMEAN: Original Mean - Weighted Mean(WTMEAN)
WTMEAN: Area-Weighted Mean

Variable	Mean	Standard Deviation	Std Error of Mean
Decade = 1			
DIF	-0.41	0.23	0.07
NEWMEAN	52.11	0.53	0.17
GP1	52.41	0.79	0.26
GP2	44.85	0.52	0.20
GP3	49.29	1.09	0.35
GP4	42.20	1.27	0.40
GP5	63.58	0.87	0.27
GP6	49.01	0.97	0.31
GP7	50.36	0.79	0.25
Decade = 2			
DIF	-0.18	0.27	0.09
NEWMEAN	51.93	0.78	0.25
GP1	51.76	0.93	0.30
GP2	43.45	0.99	0.31
GP3	48.47	0.56	0.18
GP4	42.18	1.43	0.45
GP5	63.86	0.97	0.31
GP6	49.47	1.26	0.40
GP7	50.51	1.22	0.38
Decade = 3			
DIF	-0.17	0.36	0.11
NEWMEAN	52.65	0.92	0.29
GP1	52.67	0.96	0.30
GP2	44.07	1.04	0.33
GP3	49.33	1.11	0.35
GP4	42.73	1.51	0.48
GP5	64.40	1.13	0.36
GP6	49.86	1.15	0.36
GP7	51.42	1.49	0.47
Decade = 4			
DIF	-0.42	0.39	0.12
NEWMEAN	53.41	0.89	0.28
GP1	53.08	1.03	0.33
GP2	45.45	1.74	0.55
GP3	50.44	1.32	0.42
GP4	43.45	1.67	0.53
GP5	64.75	0.99	0.31
GP6	50.44	1.11	0.38
GP7	52.46	1.58	0.50
Decade = 5			
DIF	-0.11	0.29	0.09
NEWMEAN	52.68	0.57	0.18
GP1	51.99	0.80	0.25
GP2	44.29	0.84	0.26
GP3	48.47	1.02	0.32
GP4	43.40	1.37	0.43
GP5	64.35	0.48	0.15
GP6	50.56	0.84	0.26
GP7	51.32	1.14	0.36
Decade = 6			
DIF	-0.21	0.38	0.12
NEWMEAN	52.75	0.72	0.23
GP1	52.07	1.03	0.33
GP2	44.77	1.39	0.44
GP3	49.77	0.85	0.27
GP4	43.59	1.09	0.34
GP5	64.13	1.01	0.32
GP6	50.25	0.98	0.31
GP7	51.50	1.40	0.44
Decade = 7			
DIF	-0.28	0.25	0.08
NEWMEAN	52.13	0.26	0.08
GP1	52.08	0.58	0.18
GP2	44.91	0.87	0.28
GP3	49.06	0.81	0.26
GP4	43.25	0.80	0.25
GP5	63.04	0.84	0.20
GP6	48.79	0.46	0.15
GP7	50.93	0.65	0.20

Legend of Variable Names:

DIF: Original Mean - Weighted Mean(NEWMEAN)
NEWMEAN: Area-Weighted Mean

VITA

Karen Jean Praner was born in Roswell, New Mexico, on May 9, 1952 to Mary Ann and William W. Alvey. She graduated from Roswell High School in 1969 and earned a Bachelor of Science Degree in Mathematics from Eastern New Mexico University in 1976. The author also holds a Bachelor of Science Degree in Meteorology from The Pennsylvania State University (1980). She has been on active duty in the USAF since 1977; her permanent mailing address is 906 North Plains Park Drive, Roswell, NM 88201.

END

DTIC

5-86